OPERATING INSTRUCTIONS

H-776277-9928
Job # 774567-00
BC # 544569

TYPE 1640-A,-AQ1

SLOTTED LINE RECORDER SYSTEM

(TYPE 1521-SL,-SLQ1 RECORDER)
(TYPE 900-LB PRECISION SLOTTED LINE)

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1640-A

GENERAL RADIO COMPANY

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(TYPE 1521-SL,-SLQ1 RECORDER)
(TYPE 900-LB PRECISION SLOTTED LINE)

Form 1640-0100-A
March, 1965

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GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

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TABLE OF CONTENTS

Section 1 INTRODUCTION 1

1.1 Purpose. 1
1.2 Description 1
1.3 Equipment Supplied. 2

Section 2 INSTALLATION 8

2.1 Introduction 8
2.2 Preparation For Use 10
2.3 Signal Sources 12
2.4 Coaxial Accessories Available 14

Section 3 OPERATION 16

3.1 General. 16
3.2 Preliminary Considerations 16
3.3 Preliminary Procedures 18
3.4 Measurement of VSWR. 18
3.5 Comparison Measurements 19
3.6 Measurement of Reference Plane 20
3.7 Precision Wavelength Measurement 20
3.8 Impedance Measurements. 20
3.9 Substitution Measurements 22
3.10 Strip-Chart Diagnosis 23

Section 4 SYSTEM CALIBRATION AND SPECIAL MEASUREMENTS 30

4.1 General. 30
4.2 System Calibration 30
4.3 Special Measurements. 35

Section 5 PRINCIPLES OF OPERATION 43

5.1 Introduction 43
5.2 Type 1521-SL Recorder 44
5.3 Detailed Circuit Discussion 46

Section 6 SERVICE AND MAINTENANCE 50

6.1 Warranty 50
6.2 Factory Service 50
6.3 Cleaning and Lubrication 50
6.4 Service Instructions 51
6.5 Minimum Performance Standards 51
6.6 Trouble Analysis 53
6.7 Amplifier Output Balance Adjustments 58
6.8 Servo-Motor Checks 58
6.9 Power-Line Sensitivity. 60
6.10 Slotted-Line Flatness Check. 60
6.11 Other Service Problems 60

SPECIFICATIONS

TYPE 1640-A SLOTTED LINE RECORDER SYSTEM.

Minimum Bench Space Required: Width 48 inches, depth 14 inches (1220 by 355 mm); height above bench, 12 inches, depth below bench, 9 inches (315 and 230 mm).
Accessory Required: Generator.
Net Weight: 67 pounds (31 kg).

TYPE 900-LB PRECISION SLOTTED LINE

Characteristic Impedance: 50.0 ohms ±0.1%.
Probe Travel: 50 cm. Scale calibrated in centimeters from the reference plane. Attached vernier scale can be read to 0.1 mm.
Scale Accuracy: ±(0.1 mm + 0.05%).
Frequency Range: 300 Mc/s to 9 Gc/s. At 300 Mc/s, covers a half wavelength. Operates below 300 Mc/s with GR900 Precision Air Line.
Constancy of Probe Pickup: ±0.5%.
Residual VSWR: Less than $1.001 + 0.001 \times f_{Gc}$ (e.g. 1.002 at 1 Gc/s) with GR900 connector direct.

Slotted Line Plus GR900 Adaptor

Types BNC, TNC, C	$1.006+0.016f_{Gc}$ to 1 Gc/s $1.016+0.006f_{Gc}$ from 1 to 9 Gc/s
Type N	$1.005+0.005f_{Gc}$
Type GR874	$1.001+0.016f_{Gc}$ to 1 Gc/s $1.011+0.006f_{Gc}$ from 1 to 9 Gc/s

Repeatability: Within 0.05% or 0.0005 in VSWR.
Dc Contact Resistance at Type 900-BT Connector: Inner conductor, less than 0.5 milliohm; outer conductor, less than 0.07 milliohm.
Accessories Supplied: Type 874-R22A Patch Cord; Type 900-WN Short-Circuit Termination; Type 900-WO Open-Circuit Termination; probe-tuner assembly; 1N21C and 1N23C diodes; rf probe accessory (with Type 874-BBL connector); micrometer carriage drive (accurate to 0.01 mm); storage case; Smith charts.

TYPE 1521-SL SLOTTED-LINE RECORDER

Sensitivity: Continuously adjustable from 0.05 to 2.0 mV (on-scale).
Frequency: 990 c/s ±2%.
Bandwidth: 35 c/s ±7 c/s (at 3 dB).
VSWR Range: Continuously adjustable from 1.008 (0.8%) to 1.20 (20%) full-scale; accurate to within one minor division.
Noise Level (referred to input): Short-circuit, less than 0.1 μV; open-circuit, less than 3.0 pA. Noise figure less than 5 dB at the optimum source resistance (about 30 kilohms).
Power Required: 105 to 125 or 210 to 250 V, 60 c/s, 35 W. Type 1521-SLQ1 Recorder, used with Type 1640-AQ1 System, 50 c/s.
Chart Paper: 4-inch recording on 5-inch paper; 40 minor and 8 major, or 50 minor and 10 major, divisions vertically. Horizontal scale ruling, ¼ inch.
Paper Speeds: Adjustable, 2.5 to 75 inches per minute; plots correspond to 5- to 300-cm/min carriage travel on slotted line. Two interchangeable sprockets advance paper 1 or 2 divisions per cm of probe travel.
Servo Bandwidth of Pen Drive: More than 4 c/s.
Input Connector: GR874 Coaxial Connector, locking, recessed.
Accessories Supplied: 2 pens, 2-oz. red ink, 2-oz. green ink, potentiometer cleaner, 10 rolls chart paper (100 feet each), eye-droppers for filling pen, power cord, spare fuses.

LINKAGE UNIT

Mounting Plate: Gray crackle-finished 0.250-inch aluminum plate precut to accommodate attaching hardware. Fitted with accurately spaced support blocks for Type 900-LB and low-friction bearing block, shaft and take-off gear for carriage drive. Compressible mounting feet furnish good shock isolation. Protective bumpers for slotted-line cover affixed to rear deck. Width 31, depth 6¾, height 1½ inches (790 by 175 by 40 mm). Weight 6 pounds (2.8 kg). Complete attaching hardware supplied.
Sprockets: Nickle-plated brass with ¾-inch mounting hubs. 1 cm/div — 1.41 inch diameter, 24 gear teeth. 0.5 cm/div — 2.82-inch diameter, 48 gear teeth.
Drive Chain: Flexible wire-link 4-feet long (280 links); sufficient for two chains.

U. S. Patents No. 2,581,133; 2,548,457; and 2,571,549 (lic from A.T.&T. Co.)
General Radio *Experimenter* Reference: Vol. 39, No. 1, January 1965.

DIFFERENCE DATA NOTES

Type 1640-A/-AQ1

Systems are identical except for power-input requirements for recorder units. Type 1640-A includes Type 1521-SL Slotted Line Recorder, which requires 60-c/s power input. Type 1640-AQ1 includes Type 1521-SLQ1, which requires 50-c/s power input.

Type 1521-SL

Early production units of the Type 1521-SL recorder differ slightly from the unit depicted in this manual. This difference is purely one of packaging and in no way affects electrical performance. The preamplifier subassembly, originally a plug-in type, has been made an integral part of the instrument.

RECORDER SUPPLIES AVAILABLE*

1521-9428	Chart paper - 100 foot roll (40 div.)	$2.75
1521-9310	Chart paper - 100 foot roll (50 div.)	2.75
1521-4092	16-ounce bottle of red ink	5.50
1521-4093	16-ounce bottle of green ink	5.50

* subject to quantity discounts.

Copies of Smith charts are supplied. Additional copies can be obtained from General Radio at the following prices:

Quantity	50	100	200	500	1000
Price	$ 2.00	3.75	7.00	14.00	25.00

Please specify: Impedance Coordinates (Form 5301-7569Z), Admittance Coordinates (Form 5301-7568Y), Normalized Coordinates (Form 5301-7560N), Normalized Coordinates with Expanded Center (Form 5301-7561NE), or Normalized Coordinates with Highly Expanded Center (Form 5301-7562HE).

Prices subject to change without notice.

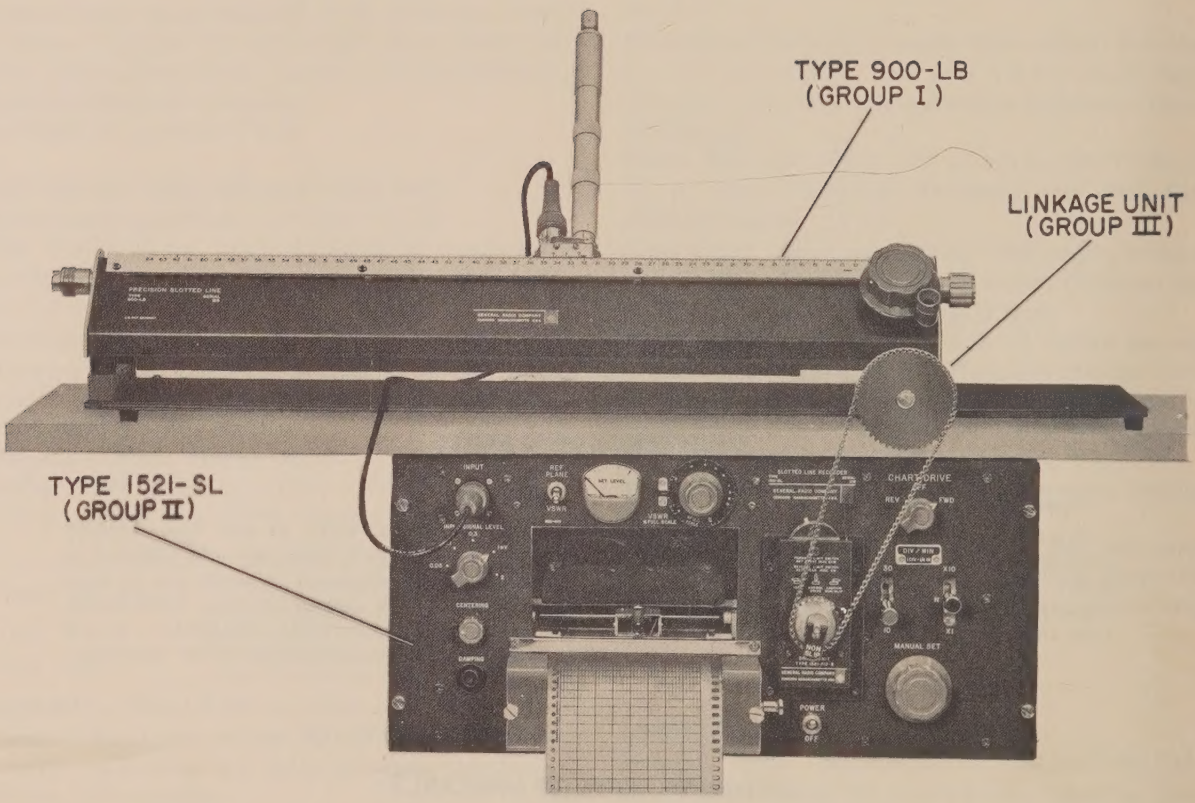


Figure 1-1. Type 1640-A Slotted-Line Recorder System.

SECTION 1

INTRODUCTION

1.1 PURPOSE.

The Type 1640-A Slotted Line Recorder System, shown in Figure 1-1, automatically produces precision-calibrated recordings of small standing-wave patterns and other slotted-line measurement phenomena. With such a system, VSWR's from 1.001 to 1.200 can be rapidly and accurately recorded.

1.2 DESCRIPTION.

1.2.1 SYSTEM.

The system consists of the Type 900-LB Precision Slotted Line equipped for automatic-recorder operation by connection to the Type 1521-SL Slotted Line Recorder via a mechanical-linkage unit, through which the recorder drives the carriage of the slotted line. The Type 900-LB fits directly on the mounting plate of the linkage unit. Carriage-drive take-off is accomplished by means of a bevel gear on the drive shaft of the slotted line. This gear meshes with a matching gear on the linkage unit, which in turn is synchronously chain-driven by the recorder drive motor.

The output of the system produces a continuous and permanent measurement record which can be analyzed graphically for the most accurate determination of the magnitude and phase of the standing-wave pattern. Positions of minima, with a short circuit at the reference plane, can also be plotted automatically. In substitution measurements, several curves can be plotted on the same record, to facilitate direct measurement of VSWR differences and cancel the effect of nonconstant probe pickup.

System accuracy derives from the 0.1-1.0% accuracy of the Type 900-LB Precision Slotted Line, the 0.05% repeatability of the GR900 Precision Coaxial Connector on the slotted line, and the wide servo bandwidth and fast writing speed of the Type 1521-SL Slotted Line Recorder. The VSWR accuracy of the strip-chart recording depends only upon three stable, wire-wound potentiometers in the servo loop, which are custom calibrated in each instrument.

The system is operated with a 1-kc square-wave modulated rf input signal, and the audio output from the slotted-line diode detector actuates the recorder for an adjustable expanded-scale VSWR presentation. Audio levels, continuously variable from 0.05 to 2 millivolts, can be accommodated by the recorder to permit on-scale operation at the level producing the best signal-to-noise ratio. The VSWR-equivalent noise level is 1.0001.

The presentation appears on a strip chart with a 4-inch recording width. The chart's vertical scale has eight or ten major divisions, each of which has five minor divisions.

The horizontal chart scale, ruled in ¼-inch intervals, can be calibrated in either 0.5- or 1.0-cm units, by selection of an appropriate drive sprocket. This scale relates directly to the centimetric probe-travel scale of the slotted line, which is calibrated with re-

spect to the reference plane located at the contact surfaces of the GR900 connector at the load end. Probe position can be plotted to 0.1-cm accuracy and can be manually reset for comparison measurements. In the chart sample shown in Figure 1-2, the full scale is calibrated for a VSWR of 1.04, so that each of the 40 divisions represents a VSWR of 1.001. The recorder is accurate to within one such minor division at any setting of the VSWR dial.

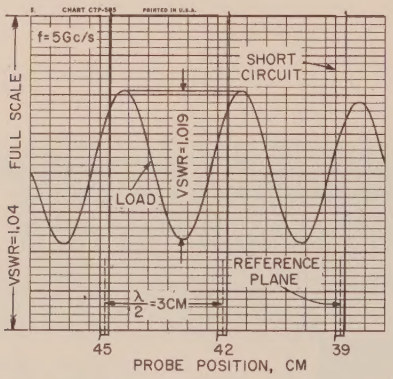


Figure 1-2. Typical readout of Type 1640-A Slotted Line Recorder System.

1.2.2 TYPE 900-LB SLOTTED LINE.

The Type 900-LB Precision Slotted Line is a coaxial instrument with a frequency capability extending from 300 Mc/s to 9.0 Gc/s. The line preserves its true coaxial cross-section, complete through the Type 900-BT Precision Coaxial Connector at the "unknown" end, without introducing step discontinuities. The residual VSWR of the line (hence, of the system) is specified identically with that of the connector, $1.001 + 0.001 \times f_{Gc}$, and typically is much lower, as is shown in Figure 1-3. It is supplied with a complete set of accessories, including diode detector, adjustable probe-tuner assembly and Type 900-WO Precision Open-Circuit and Type 900-WN Precision Short-Circuit Terminations. The line is equipped for measurements of devices fitted with the GR900 connector, but it is easily adapted to General Radio Type 874 and other leading 50-ohm coaxial connector systems. The Type 900-LB can be simply lifted off the linkage unit and incorporated in a slotted-line equipment setup containing any commercially available SWR indicator.

NOTE

Complete instructions for the Type 900-LB are supplied in a separate manual.

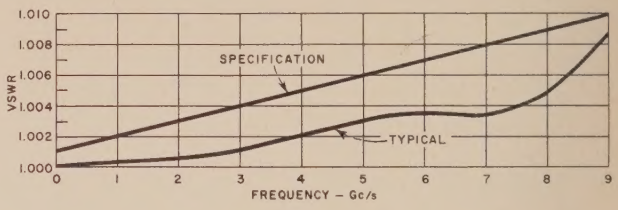


Figure 1-3. Residual VSWR of Type 1640-A system.

1.2.3 TYPE 1521-SL RECORDER.

The Type 1521-SL Slotted Line Recorder is a transistorized, single-channel, servo-type instrument. It produces an ink record on white chart paper, translucent for reproduction. Edge perforations on the paper mesh with drum-mounted sprockets, to advance the strip. The reversible paper feed offers both manual and automatic options, with four switch-selectable motor speeds available in the automatic mode. Rotary tripping switches can be preset to limit motor drive and probe travel in either direction.

The capillary pen is moved across the chart paper by a null-seeking servo which travels linearly (over a 4-inch span) in a uniform magnetic field. The difference between the 1-kc slotted-line detector-output voltage and an internal reference voltage is amplified and used as the error signal to position the pen. A contact attached to the servo motor rides along a straight-line potentiometer, which is the balancing element. A velocity-feedback coil, also mounted on the servo-motor frame, furnishes appropriate damping.

Front-panel controls provide continuous, calibrated, full-scale adjustment over the VSWR range. A gain control and associated level meter ensure operation within the square-law range of the slotted-line diode detector. The gain of the recorder can be increased, by a front-panel toggle-switch setting, to effectively give a 20-times magnification to recorded null positions of the slotted line. Thus, the very deep minima occasioned by reference-plane terminations can be plotted in their narrowest portions for maximum accuracy.

1.3 EQUIPMENT SUPPLIED (See Figures 1-4 through 1-6).

Equipment supplied with the Type 1640-A system is listed in Table 1-1.

TABLE 1-1
LIST OF EQUIPMENT SUPPLIED - TYPE 1640-A
(See also Figures 1-4 through 1-6)

Group	*Fig*	*Ref*	*Name*	*Function*	*Part No.*
I	1-4	(1)	Rf Probe Accessory	Probe for use with unmodulated rf signal source	0874-4670
		(2)	Type 900-WO	Precision Open-Circuit Termination	0900-9981
		(3)	Type 900-WN	Precision Short-Circuit Termination	0900-9971
		(4)	Type 900-LB Precision Slotted Line (includes carriage)	Measuring instrument	0900-9651
		(5)	Adjustable-Probe-Tuner Assembly	Mount adjustable pickup probe and tune it to resonance	0900-3070
		(6)	Storage Case	Store slotted line and accessories	0900-2210
		(7)	Type 1N21C Diode Type 1N23C Diode	Detector Detector	6084-1005 6084-1007
		(8)	Type 874-R22A	Coaxial patch cord	0874-9682
		(9)	Micrometer Drive Assembly	Position carriage to 0.01-millimeter accuracy	0900-3100

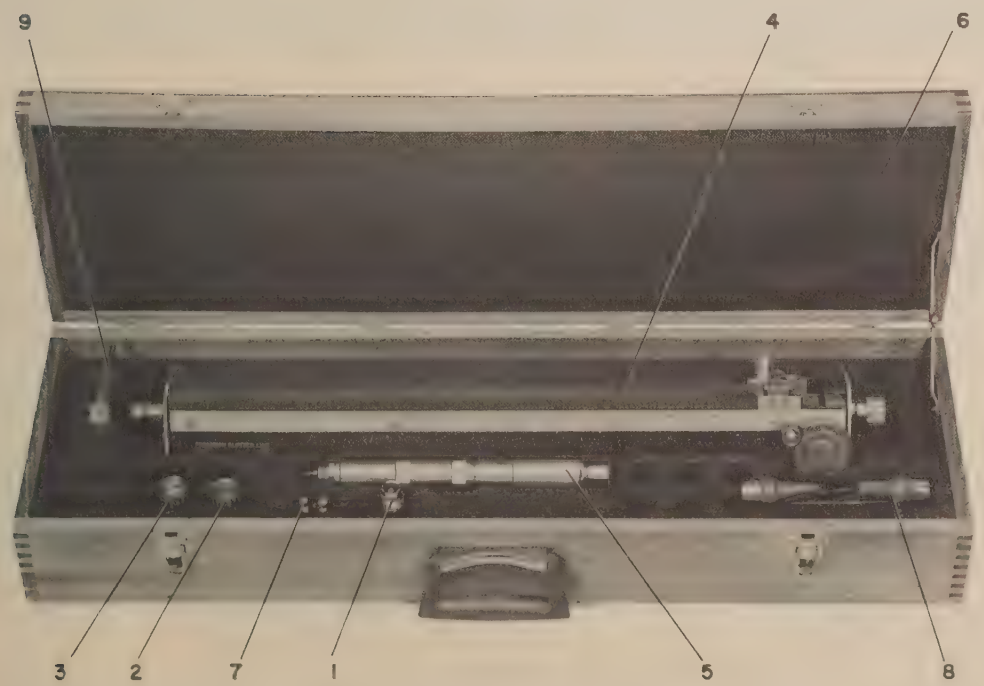


Figure 1-4. Type 900-LB Slotted Line and Accessories — Group I.

TABLE 1-1 CONTINUED

Group	*Fig*	*Ref*	*Name*	*Function*	*Part No.*
II	1-5	(1)	Type 1521-SL Slotted-Line Recorder	Recording instrument	1521-9561*
		(2)	Chart paper, 100-foot roll (5)	Recorder supply	1521-9428
		(2)	Chart paper, 100-foot roll (5)	Recorder supply	1521-9310
		(3)	Type CAP-22 Cable	Power cord, 3-terminal	4200-9622
		(4)	Fuses (2):		
			0.5 amp (115-volt models only)	Power-line spare	5330-1000
			0.25 amp (230-volt models only)	Power-line spare	5330-0700
		(5)	Pen sets (2)	Glass recorder pen, cap, and cleaning wires	1521-3490
		(6)	Eyedroppers (2)	Fill pen with ink	1521-4190
		(7)	Red ink (2-oz bottle)	Supply for pen	1521-4090
		(7)	Green ink (2-oz bottle)	Supply for pen	1521-4091
		(8)	"NO-OX" (2-oz bottle)	Cleaning solvent and lubricant	1521-4200

*Type 1521-SLQ1 — 1521-9571

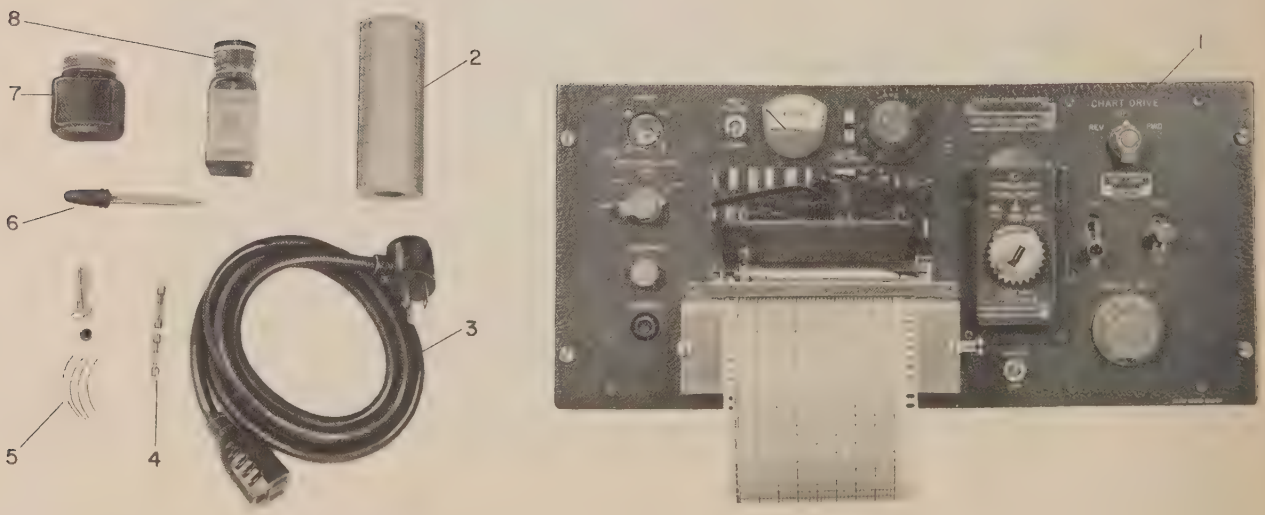


Figure 1-5. Type 1521-SL and accessories supplied — Group II.

TABLE 1-1 CONTINUED

Group	*Fig Ref*		*Name*	*Function*	*Part No.*
III	1-6	(1)	Mounting plate assembly	Position units in Groups I and II for operation and support drive shaft	1640-2000
		(2)	Sprocket assembly, large	Drive slotted-line probe 0.5 cm per division on chart paper	1640-1010
		(3)	Sprocket assembly, small	Drive slotted-line probe 1.0 cm per division on chart paper	1640-1020
		(4)	Drive chain (260 link)	Power transport link chain	4280-0800
		(5)	Mounting hardware	Attach mounting plate and Type 1521-SL to bench and to one another	Various

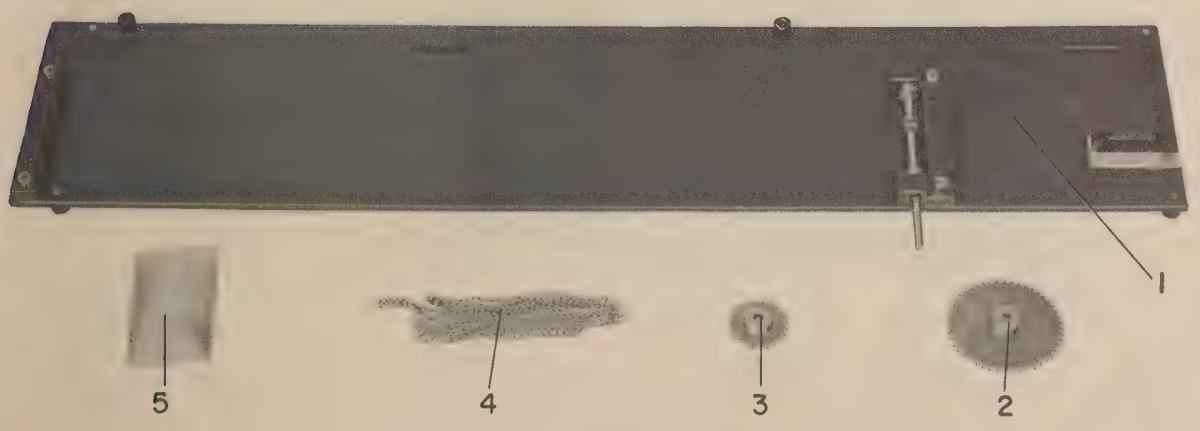


Figure 1-6. Linkage Unit — Group III.

1.4 CONTROLS AND INDICATORS (Figure 1-7).

Controls and indicators for the Type 1640-A Slotted Line Recorder System are listed and described in Table 1-2.

TABLE 1-2
CONTROLS AND INDICATORS - TYPE 1640-A
(See Figure 1-7)

Name	*Fig 1-7 Ref*	*Type*	*Function*	*Related Indicator*
CHART DRIVE	1	3-position rotary switch	Start, stop, advance, and reverse chart paper	Chart-paper movement
DIV/MIN 30 - 10	2	2-position lever (left-hand)	Basic speed control for chart paper	Used with item 3
DIV/MIN X10, N, X1	3	3-position lever (right-hand)	Speed multiplier for chart-paper drive	Used with item 2
MANUAL SET	4	Rotary drive	Manual paper drive control [with (3) in neutral, N]	Chart-paper movement
DRIVE UNIT Type 1521-P10-B	5	Rotary adjustable micro-switch actuator	Bidirectional limit control for carriage drive	Carriage movement
DRIVE UNIT Type 1521-P10-B	6	3-position lever	Clutch to connect chart-paper drive take-off to slotted-line carriage drive	See engraving on unit
POWER	7	2-position toggle switch	Main ac power control	Chart-paper lights
DRIVE UNIT OUT	8	2-position toggle switch	Disables limit switches on drive unit	Carriage moves to stops
Chart paper	9	5-inch paper with grid ruling	Plots standing-wave pattern in slotted line	Final product of system
Pen	10	Retractable glass pen	Plots standing-wave pattern in slotted line	Chart paper - use only with General Radio Type 1521-4090 or -4091 ink
DAMPING	11	Rotary potentiometer-depress with thumb to operate	Noise sensitivity adjustment for pen drive	Pen jitter
CENTERING	12	Rotary potentiometer	Centers pen excursions in chart paper	Pen and chart paper
INPUT SIGNAL LEVEL	13	Rotary potentiometer - usual setting around 1 mV	Continuous control, 0.05 to 2 mV	SET LEVEL meter
REF PLANE/VSWR	14	2-position toggle switch	Selects VSWR or reference-plane plots	Chart paper
SET LEVEL	15	Meter	Indicator for audio output from slotted-line probe	Pen movement
VSWR % FULL SCALE	16	Rotary potentiometer	Controls scale expansion of VSWR plots - 0.8% to 20% full scale	Chart paper
Scales	17	Metric vernier, lineal	Indicates probe position, relative to reference plane, to 0.1-mm accuracy	Chart paper, when motor drive engaged
Scale	18	Metric vernier, rotary	Indicates probe-tuning-stub cavity size	SET LEVEL meter peaked at optimum tuning
Scale	19	Micrometer, 0.001-inch min.	Controls probe penetration - 0.010–0.150 inch	SET LEVEL meter - increases as depth increases

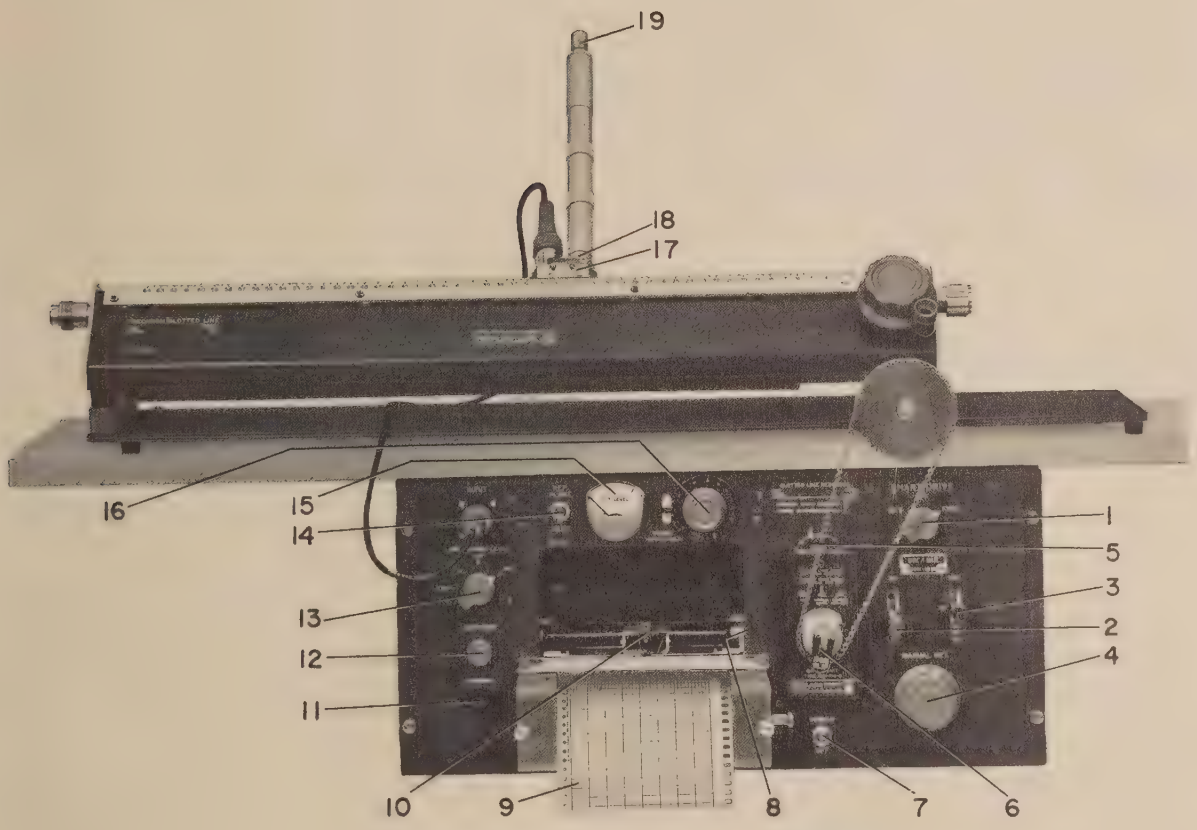


Figure 1-7. Type 1640-A controls and indicators (Table 1-2).

SECTION 2

INSTALLATION

2.1 INTRODUCTION.

2.1.1 GENERAL.

This section covers the installation of the Slotted Line Recorder System, the attachment of removable components, and recommendations on accessory equipments.

The Type 1640-A is a bench-mount system compatible for use with benches commonly found in microwave laboratories. There are two recommended mounting configurations which provide for effective utilization of bench space and for convenient operation. Ordinarily, the mounting plate is affixed to the top of the bench, one edge parallel with the front edge of the bench; the Type 900-LB is mounted on the plate, and the Type 1521-SL beneath the bench, either suspended from the top or supported on a shelf directly beneath the other equipment. After the respective components have been arranged in proper relationships, the mounting hardware should be installed and the drive chain cut to length and slipped over the sprockets.

2.1.2 INSTALLATION WITH RECORDER SUSPENDED (Figures 2-1 and 2-2).

Select a portion of bench space, approximately 6 feet across, which has a plain, table-like top 1 inch or less thick. A bench top with a set-back vertical facing immediately below it is not suitable without modification. Proceed as follows:

a. In the center of the selected surface, drill two ¼-inch holes in line, one $3\frac{3}{16}$ inches from the edge of the bench and the other 6¼ inches from the edge.

b. Drill two more holes 18 inches to the right of the first pair, the same depths in from the edge.

c. Unpack the Group III items supplied (Table 1-1) and select two 10-32 × 2¾-inch binder-head screws and two no. 10 flat washers. Insert one screw (with one washer) down through each of the holes nearer the edge of the bench.

d. Unpack the Type 1521-SL Recorder (Group II item) and remove the instrument from its case. Place the empty case under the bench so that the two screws in the bench pass through the forward holes in the top surface of the aluminum end frames. Temporarily support the case in this position.

e. Over each screw, slip a no. 10 lock washer, thread on a wing nut and tighten with a screwdriver.

f. Pass a 10-32 × 2¾-inch binder-head screw up through the right-rear clearance hole in the recorder end frame and through the hole in the bench. Install a flat washer and a no. 10 hexagonal nut on the screw, and tighten firmly.

g. Install the remaining screw in the end frame at the other end of the recorder in the same way.

h. Add the second hex nut then the flat washer to each screw and thread the nut to within $\frac{1}{16}$ inch of the first nut.

i. Place the mounting plate on the bench with the drive shaft up and facing out. Align the slots in the rear of the plate with the two screws protruding

from the bench. The drive shaft should protrude about 1 inch beyond the edge of the bench.

j. Install the remaining flat washers, thread the wing nuts on each screw, and tighten gently.

k. Lock the upper hex nuts against the bottom of the plate (refer to step h).

l. Install the recorder in its case.

m. Select the appropriate sprocket for the scale expansion desired (refer to Table 3-2), and mount the sprocket, hub-end first, on the protruding drive shaft on the mounting plate. Tighten the set screws with a $^{3}/_{32}$-inch Allen-head wrench. The sprocket should clear the bench edge and align vertically with the sprocket on the recorder.

n. Loosen the wing nuts at the top rear of the mounting plate and slide the plate over so that the screws strike the right ends of the slots.

o. Drape the drive chain over the sprocket and pass it under the sprocket on the Type 1521-SL. Estimate a correct length to give a slightly slack fit, open the appropriate link, and separate the surplus chain. Rejoin the links so that the chain is a closed loop connecting the sprockets. Save the unused chain for use with the other sprocket.

p. Slide the mounting plate to the right to take up the slack in the drive chain and finger-tighten the wing nuts.

q. Open the storage case of the Type 900-LB, grasp the instrument by the connectors at the ends, lift it out, and set it on the raised bearing blocks on the mounting plate. The feet of the slotted line fit over the screwheads in the bearing block.

r. Adjust the bevel gears on the drive shafts of the slotted line and mounting plate so that a good mesh is achieved.

2.1.3 SHELF MOUNT.

Another mounting arrangement is that in which the Type 1521-SL is supported beneath the Type 900-LB by a shelf. This configuration permits rapid change of slotted-line drive speed, as it allows the Type 1521-SL to be repositioned to compensate for changes in the

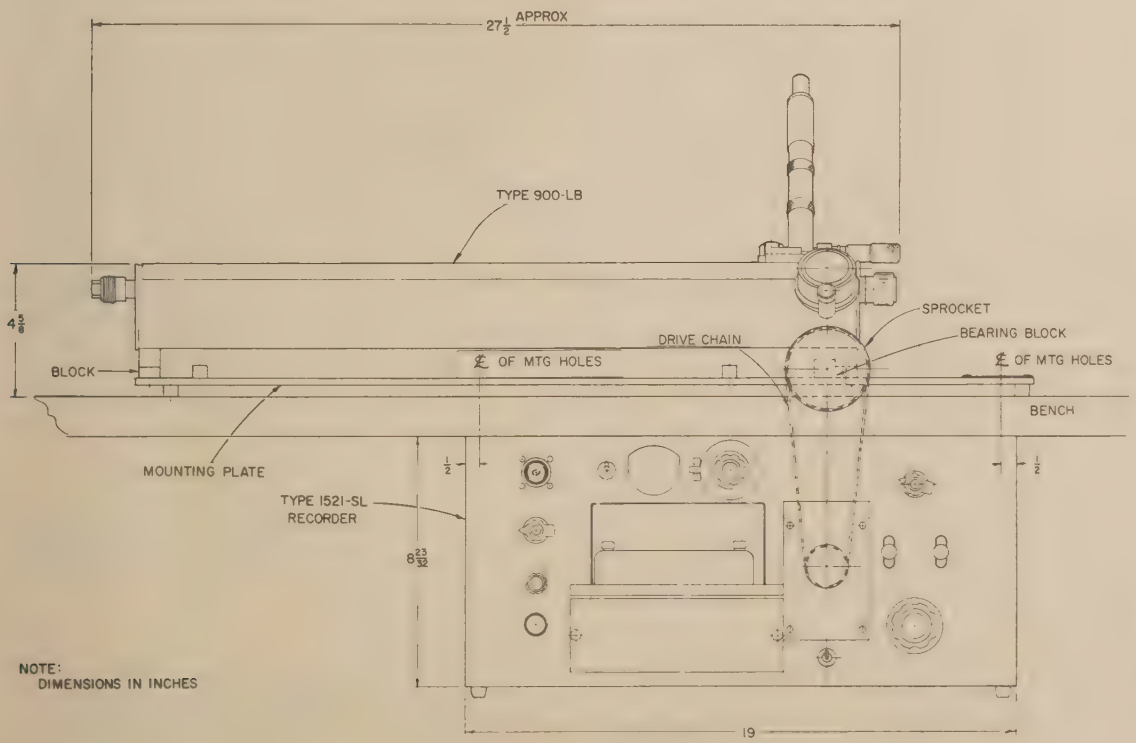


Figure 2-1. Front view of bench installation of Type 1640-A with Type 1521-SL suspended.

effective length of the drive chain occasioned in switching from one drive sprocket to the other; both sprockets can be attached to the mounting plate.

A 3-foot-wide shelf at least 1 foot deep, not less than 9 inches below the lower surface of the top of the bench, capable of supporting up to 70 pounds, is recommended.

2.1.4 BENCH-TOP MOUNT.

A third, but less attractive mounting option is placement of the Type 1521-SL on a bench top with the mounting plate and the slotted line installed on top of it. However, the controls on the slotted line are less convenient to reach and the indicators much harder to read. Only the rear two screws are used to attach the mounting plate to the recorder.

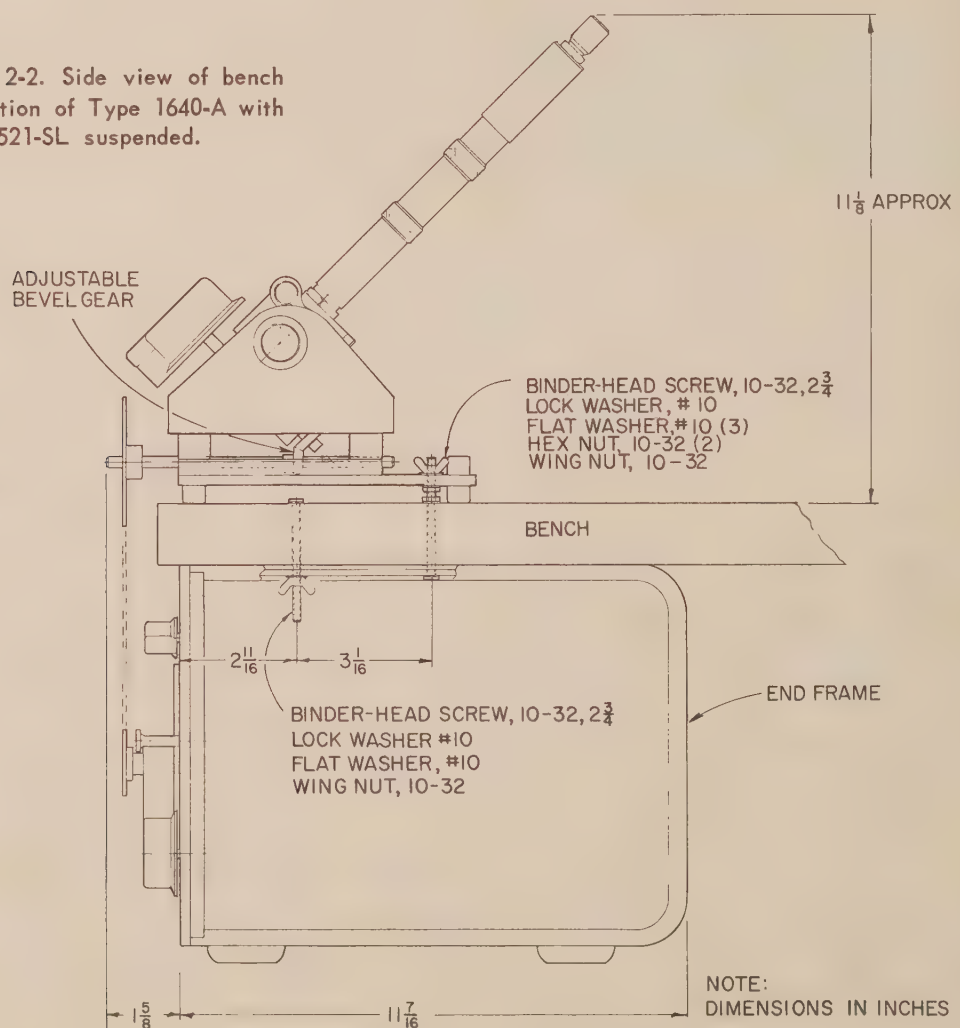
2.2 PREPARATION FOR USE (See Figure 1-4).

2.2.1 SLOTTED LINE ASSEMBLY.

Observe the following procedures to assemble the slotted line:

a. Tip out the rear cover panel of the slotted line and bring it to rest on the bumpers behind the instrument.

Figure 2-2. Side view of bench installation of Type 1640-A with Type 1521-SL suspended.



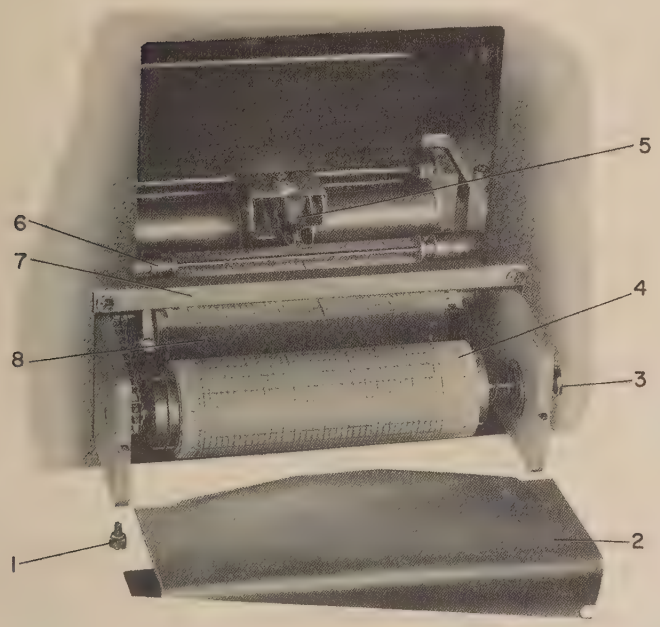


Figure 2-3. Front oblique view of recorder.

b. Mount the Micrometer-Drive Assembly on the slotted line.

c. Install the micrometer drive on the rear guide rod. Finger-tighten the thumbscrew at the base and tip the assembly to a retracted position, to clear the carriage until ready for use.

d. Remove the tuning stub from the case. Remove the plastic tip protector.

e. Be sure that the probe-penetration indicator reads 0.100 or greater, then thread the probe-tuner into the empty socket in the top of the carriage. Tighten it with a 7/8-inch open-end wrench; apply 1 foot-pound torque maximum.

CAUTION

The diode holder must be empty when probes are installed or removed, since the diode might bend or scratch the probe tip.

f. Remove the knurled aluminum cover at the rear of the carriage to expose the diode holder.

g. Select the appropriate diode (refer to paragraph 3.2.2), remove it from the container, and plug it into the opening in the holder. The small end goes in first and the diode bottoms in its holder. Type numbers are marked on the diodes.

h. Reattach the diode cover hand-tight.

i. Remove the Type 874-R22A Patch Cord from the storage case and attach one end to the Type 874 connector on the carriage of the Type 900-LB. Pass the other end under the slotted line from the rear and attach it to the INPUT connector of the Type 1521-SL.

j. Look in the slotted-line storage case for the open- and short-circuit terminations. Other nests are available for the storage of small accessories.

CAUTION

Retain all plastic covers supplied to protect the precision finished surfaces.

2.2.2 PAPER LOADING (Refer to Figure 2-3).

To load the recorder with paper, proceed as follows:

a. Remove the two thumbscrews (1) and remove the paper cover (2).

b. Pull out the spring-loaded paper knob (3), and insert the roll of paper (4), with the oversize perforations facing the knob (to the right).

c. Grasp the pen (5) and swing it up, away from the drum.

d. Guide the paper under and around the drum (8).

e. Set the gear-shift lever to N and turn the MANUAL SET knob clockwise. Let the pins pull the paper under the rollers (6).

f. Reattach the paper cover and fasten it with the two thumbscrews.

g. Advance the paper with the MANUAL SET knob, over the top of the paper cover and under the tear gate (7). It may be necessary to push down slightly on the paper cover for clearance.

h. To tear the paper, lift it from one edge against the tear gate. The paper cover provides a convenient writing surface.

2.2.3 PEN INSTALLATION.

Install the pen in the recorder by the following procedure:

a. Carefully open one of the packages containing the pen assembly and cleaning wires and remove the pen. Retain the pack to prevent loss or damage to the spare wires.

b. Remove the red plastic cover from the pen assembly and use the eyedropper to fill the glass reservoir (about $^4/_5$ full) with the appropriate-colored ink.

c. Grasp the tip of the wire protruding from the center of the pen point and slowly withdraw the wire.

d. When the wire is removed, save it with the spares for later cleaning use.

e. Replace the red cover on the reservoir and run the point gently on a scrap of chart paper to make sure that the ink is flowing properly.

f. Insert the pen reservoir in the semicircular clips in the pen holder and press it back until the neck of the pen rests against the fork at the front of the pen holder.

g. Tip the pen up until ready for use.

2.2.4 PEN REFILL.

To refill the pen, pull the glass reservoir gently from its clamping spring to remove it. Remove the cap and, with the eyedropper, fill the tube, no more than $^4/_5$ full, with the ink supplied. Then, replace the cap, pivot the pen holder up, and push the pen assembly back into place, with its point held in position by the front mounting fork.

CAUTION

Don't permit the reservoir to empty completely. Ink left in the pen for more than two days may dry, clogging it. Use ink supplied by General Radio.

When the cap is replaced, make sure that its air hole is not clogged. If ink does not flow through the capillary tube to the point, the air may be removed with the eyedropper. Leave the pen up (away from the paper) until ready to record.

2.2.5 POWER CORD.

Connect the power cord to the three-prong connector at the rear of the recorder. A small nameplate to the right of this connector indicates the voltage and frequency for which the recorder is wired. A good ground connection should be made to the third conductor of the power cable to prevent 60-cycle pickup.

The recorder, normally supplied wired for 115-volt operation, can be rewired for 230-volt use as shown on the schematic diagram (Figure 6-10).

2.3 SIGNAL SOURCES.

2.3.1 GENERAL.

The Type 1640-A requires only a laboratory-quality rf signal source with 1-kc square-wave modulation to be ready for operation. The requirements on the signal sources for Type 1640-A measurements are more severe than those for measurements with conventional standing-wave indicators. This is so because of the extreme expansion available with the Type 1521-SL recorder, which magnifies amplitude irregularities and frequency instability that might normally go unnoticed.

In general, the signal sources must meet the following requirements:

1. Short-term amplitude instability, less than 0.02% rms.
2. Short-term frequency instability less than 20 ppm.
3. Short-term frequency stability of 1-kc modulation, better than 1 cps.
4. Tuning range of 1-kc modulation, ±3%, minimum.
5. Sensitivity of signal source to line-voltage changes, less than ±0.05% change in indication on chart paper for ±10-volt change in line voltage about nominal.
6. Power output, 1 milliwatt minimum.
7. Well-shielded rf output.

Oscillators having regulated power supplies are generally required to meet these specifications. As an alternative, the line voltage may be regulated with a Type 1570-A Automatic Voltage Regulator to improve the performance of a marginal signal source.

Table 2-1 lists recommended General Radio instruments to fulfill the signal-source function; suggested setups are shown in Figures 2-4 through 2-6.

TABLE 2-1
RECOMMENDED INPUT EQUIPMENT* FOR USE WITH TYPE 1640-A

Freq Range Gc/s	Source: Osc Type	Source: Power Supply Type	Modulator: Osc	Modulator: Power Supply	Variable Attenuator Type	Termination Type	Filter Type	Fixed Attenuator Type	Fig Ref
0.18 - 0.60	1209-CL	1267-A	1210-C	1201-B	N.A.†	N.A.	874-F500L	874-G20L	
0.25 - 0.96	1209-C	1267-A	1210-C	1201-B	N.A.	N.A.	874-F1000L	874-G20L	2-5
0.90 - 2.00	1218-A	1267-A	1210-C	1201-B	N.A.	N.A.	874-F2000L	874-G20L	
1.70 - 4.10	1360-B	N.A.	N.A.	N.A.	N.A.	N.A.	874-F4000L	874-G20L	2-4
3.84 - 4.46	1220-A4	1201-B	1210-C	1201-B	874-GAL	874-W50BL	874-F4000L	874-G20L	
4.24 - 4.91	1220-A5	1201-B	1210-C	1201-B	874-GAL	874-W50BL	———	874-G20L	
5.10 - 5.90	1220-A6	1201-B	1210-C	1201-B	874-GAL	874-W50BL	———	874-G20L	
5.92 - 6.45	1220-A7	1201-B	1210-C	1201-B	874-GAL	874-W50BL	———	874-G20L	2-6
6.20 - 7.42	1220-A8	1201-B	1210-C	1201-B	874-GAL	874-W50BL	———	874-G20L	
7.42 - 9.00	1220-A**	1201-B	1210-C	1201-B	874-GAL	874-W50BL	———	874-G20L	

* Or equivalent

**With 2K25: 8.550 - 9.660 Gc/s.

† N.A. - Not applicable.

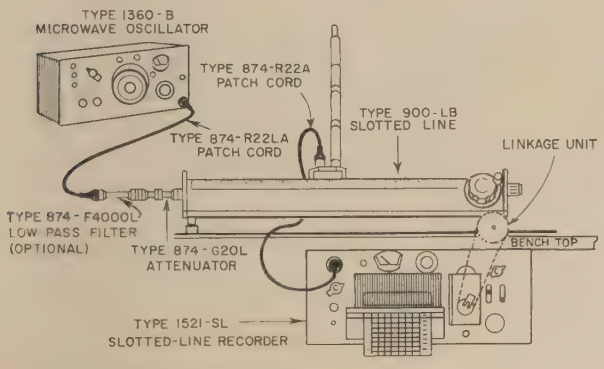


Figure 2-4. Equipment set-up for the use of the Type 1640-A with the Type 1360-B Microwave Oscillator.

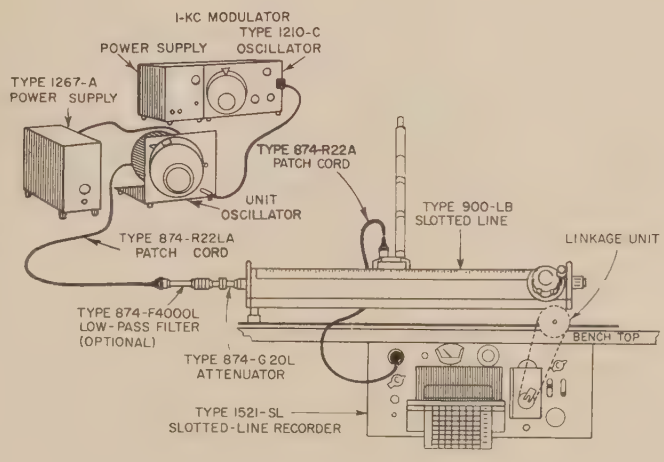


Figure 2-5. Equipment set-up for the use of the Type 1640-A with GR Unit Oscillators.

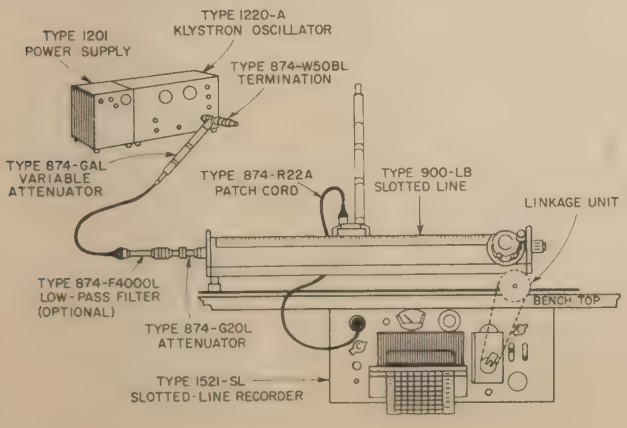


Figure 2-6. Equipment set-up for use of the Type 1640-A with the Type 1220-A Klystron Oscillator.

2.3.2 OSCILLATOR ISOLATION.

Slotted-line measurement errors can be caused by shifts in the oscillator frequency with changes in load impedance. Oscillators that are tightly coupled to the line can have relatively large frequency shifts. This effect can be greatly reduced by the insertion of a fixed attenuator, such as a Type 874-G20L, 20-dB coaxial attenuator, between the oscillator and the slotted line (refer to Table 2-1).

The attenuators are fitted with Type 874 connectors at both ends; locking versions are required for low leakage. They are single-section, T-type resistance pads, capable of improving the match of sources to 50 ohms, over the frequency range of the Type 900-LB.

For applications that require maximum power transfer, the use of a ferrite isolator between the oscillator and the slotted line is recommended.

2.3.3 CONTROL OF HARMONICS.

Another possible source of error in slotted-line measurements is the presence of harmonics generated by the driving oscillator. A small harmonic-voltage content in the signal may produce a harmonic signal many times that of the fundamental at a deep minimum point. Therefore, if the detector will respond at all to harmonics, difficulty may be encountered.

The tuned diode detector may not have a large amount of rejection for various harmonics because the tuning stub has higher-order resonances. Insertion of a Type 874-F low-pass filter between the oscillator and the line can reduce the harmonics to an insignificant value.

The Type 874 filters called out in Table 2-1 are useful at frequencies up to 4.0 Gc/s. They are coaxial filters of the Tschebyscheff type, which produce a very steep cutoff characteristic and a stop-band typically 50-dB down. They come with locking Type 874 connectors at both ends for minimal leakage.

2.3.4 FREQUENCY-MODULATION PROBLEMS.

Square-wave modulation must be used to minimize frequency modulation of the signal source. The Type 1210-C RC Oscillator with the Type 1201-B Unit Regulated Power Supply is recommended for use with those oscillators listed in Table 2-1 that require external modulators. The Type 1360-B and the Type 1220-A have internal modulators.

2.3.5 RF LEAKAGE PROBLEMS.

The connections between the signal source and the slotted line must be well-shielded to prevent leakage of energy from this point in the system. Leakage here can re-enter the system through the slot in the slotted line and cause erroneous VSWR indications. The symptom of this condition is movement of the pen when the slotted-line carriage or the input cable is handled. Make sure that all rf connectors used are low-leakage types, i.e., Type 874 locking connectors or type-N. All connector joints must be firmly made.

2.4 COAXIAL ACCESSORIES AVAILABLE.

Coaxial devices under test, equipped with the Type 900-BT Precision Coaxial Connector, may be attached directly to the slotted line. Adaptors are available to permit use of the slotted-line recorder for measurements on devices fitted with Type 874 and other popular 50-ohm coaxial connectors. In fact, the attachment of such adaptors readily converts the Type 900-LB to a slotted line with performance characteristics that equal or surpass most commercial equipment designed specifically for those line sizes. The adaptors and other coaxial devices in the GR900 series, suitable as accessories to the slotted line but not supplied, are listed and described in Table 2-2.

Type 874 coaxial accessories particularly useful at the input of the slotted line are covered in subsequent paragraphs. A complete table of GR874 components is given at the back of the manual.

TABLE 2-2.
GR900 COAXIAL ELEMENTS AND EQUIPMENT

ADAPTOR

Type	*Function*
900-Q874	Connects to GR874
900-QBJ	Connects to type-BNC Plug
900-QBP	Connects to type-BNC Jack
900-QCJ	Connects to type-C Plug
900-QCP	Connects to type-C Jack
900-QNJ	Connects to type-N Plug
900-QNP	Connects to type-N Jack
900-QTNJ	Connects to type-TNC Plug
900-QTNP	Connects to type-TNC Jack

AIR LINES — PRECISION

900-L10	Phase, Time-Delay & Impedance Standard — 10 cm
900-L15	Phase, Time-Delay & Impedance Standard — 15 cm
900-L30	Phase, Time-Delay & Impedance Standard — 30 cm

AIR LINES — REFERENCE

900-LZ5	Ultraprecise Impedance Standard — 5 cm
900-LZ6	Ultraprecise Impedance Standard — 6 cm
900-LZ7H	Ultraprecise Impedance Standard — 7.5 cm
900-LZ10	Ultraprecise Impedance Standard — 10 cm
900-LZ15	Ultraprecise Impedance Standard — 15 cm
900-LZ30	Ultraprecise Impedance Standard — 30 cm

CONNECTOR & CONNECTOR KITS

900-BT	GR900 Precision Connector
900-AB	GR900 Coupling Hardware Kit

CONNECTOR & CONNECTOR KITS continued

Type	*Function*
900-AC	GR900 Contact & Coupling Hardware Kit
900-AP	GR900 Coupling Hardware & Center Tip (for custom reference air line use)

TERMINATIONS

900-W50	50-Ohm Standard
900-W100	100-Ohm Standard
900-W200	200-Ohm Standard
900-WO	Precision Open Circuit
900-WO4	Open Circuit (with WR's)
900-WN	Precision Short Circuit
900-WNC	Reference Line Short Circuit
900-WNE	Short Circuit (Coplanar with Type 900-WO)
900-WN4	Short Circuit (with WR's)
900-WR110	Standard Mismatch (VSWR = 1.1)
900-WR120	Standard Mismatch (VSWR = 1.2)
900-WR150	Standard Mismatch (VSWR = 1.5)

MISCELLANEOUS

900-LB	Precision Slotted Line
1640-A	Slotted Line Recorder System
900-TOK	GR900 Connector Tool Kit
900-TUA	Tuner (1.0 - 9.0 Gc/s)
900-TUB	Tuner (0.25 - 2.5 Gc/s)
0900-9508	Precision Inner-Conductor Rod
0900-9509	Precision Outer-Conductor Tube
0900-9782	Adaptor Flange

SECTION 3

OPERATION

3.1 GENERAL.

Upon completion of the appropriate equipment setup as indicated in Section 2, apply power to the source and allow for required warm-up time.

NOTE

Detailed operating instructions for the Type 900-LB are supplied in a separate manual.

3.2 PRELIMINARY CONSIDERATIONS.

3.2.1 MATING OF TYPE 900-BT CONNECTORS.

To attach the unknown to the slotted line, one Type 900-BT locking nut must be placed in the storage position, since only one can be used at a time.

a. To store the locking nut, slide it back until the threads engage. Then thread it back off the centering-gear ring and slide it to the ridge at the rear of the coupling nut (Figure 3-1).

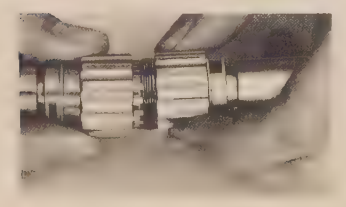


Figure 3-1. Mating of Type 900-BT connectors.

b. Move the locking nut of the other connector back slightly. Align the connectors axially and engage the teeth of the centering-gear rings in any convenient orientation.

c. Hold the connectors in the joined position, thread the active locking nut over the centering-gear ring of the mating connector, and hand tighten.

3.2.2 DIODE SELECTION.

The choice of detector diode used in the slotted line depends upon operating frequency, since such diodes have a self-resonant frequency which may reduce sensitivity slightly and broaden the tuning-stub resonance. Two microwave diodes (types 1N21C and 1N23C) with different resonant frequencies are supplied in the Type 900-LB storage case. If the above condition is encountered, it can be eliminated by interchange of diodes.

3.2.3 PROBE PENETRATION.

The probe mounted in the tuning stub can be adjusted for depth-of-penetration to give adequate sensitivity with minimal effect on the standing-wave pattern. The presence of the probe affects the residual VSWR of the line, if the probe is too tightly coupled and the signal source is not well matched. The probe reflection, after re-reflection from a mismatched source, adds to the residual VSWR of the slotted line.

The effect of the probe coupling can be determined by measurement of the VSWR at two different probe depths. If the measured VSWR is the same at both, the penetration is correct and the probe coupling used has no significant effect on the measurement. If the measured VSWR's are different, additional measurement should be made with decreasing amounts of probe penetration, until no difference remains.

Adjust probe penetration by means of the small control knob at the top of the tuning stub. Set it at 0.100 for routine measurements. The adjustment scale is calibrated in thousandths of an inch and reads the distance between the tip of the probe and the center conductor of the slotted line. A stop, which prevents the probe from touching the center conductor, holds the minimum distance to about 0.010 inch; maximum gap is about 0.150 inch.

3.2.4 TUNING STUB ADJUSTMENT.

Rotate the knurled barrel to adjust the tuning stub for maximum output as monitored on the SET LEVEL meter. Readjust the signal level as necessary to keep the audio output of the diode below the black wedge on the meter. Final tuning may be done with pen deflection serving as the tuning indicator.

NOTE

Tuning is preferably done with a Type 900-W50 50-Ohm Termination on the line to minimize the possibility of tuning to a harmonic of the signal source, although tuning with the Type 900-WO Termination supplied is satisfactory.

The scale on the lower part of the tuning stub reads the position of the sliding short-circuit within the barrel. It is calibrated in centimeters, one per turn, with marks on the barrel every 0.1 cm. A family of resonance curves for the stub is given in Figure 3-2 as a guide in choosing the approximate setting for any source frequency. When the slotted line is operated at 2.0 Gc/s, curve B indicates that the stub should be set approximately at 4.5 cm, initially, and adjusted slightly around this setting for peak output.

The curves overlap and the extent of overlap increases at higher frequencies; thus, multiple resonance points occur. For high-Q performance, use the curve corresponding to the lower setting on the cm scale. For example, when the slotted line is operated at 3.0 Gc/s, the 1.0-cm setting indicated by curve B, rather than the 6.0-cm setting indicated by curve C, should be used.

Above, 1.5 Gc/s, to be sure that the tuning stub is not set to a harmonic of the source frequency, tune

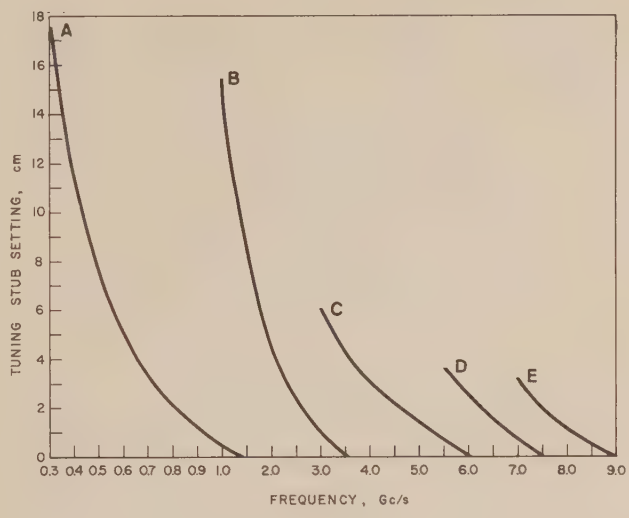


Figure 3-2. Preferred Type 900-LB tuning stub settings.

to two adjacent maxima on the *tuning stub*. The difference (in cm) should equal one-half wavelength at the source frequency. Below 1.5 Gc/s, to check the tuning-stub setting, measure the distance between two adjacent minima on the *slotted line*, with either the Type 900-WN or the Type 900-WO termination on the line. This distance should also be one-half wavelength.

3.2.5 DRIVE UNIT LIMIT ADJUSTMENT.

The Type 1521-P10-B Drive Unit contains two microswitches which can be preset to stop the motor at selected limits of probe travel. This feature protects the various elements of the linkage and facilitates repeated measurements over a limited section of the slotted line.

The stops are set by means of two serrated disks at the top of the unit. The white rod protruding from each disk opens a microswitch at the right side of the unit to stop the motor; the drive must be reversed to restart the motor.

The outer disk is the FORWARD limit switch and the inner disk is the REVERSE limit switch. The slotted-line carriage should be positioned manually, with all the linkages connected, and the appropriate disk advanced until the click of the microswitch corresponds to the desired limit of probe travel. If desired, the microswitches can be disabled when the toggle switch marked DRIVE UNIT OUT, which is behind the front panel, is thrown to the OUT position.

Instructions are printed on the front panel of the drive unit for ready reference.

3.2.6 RECORDER ADJUSTMENTS.

Before application of power to the Type 1521-SL Slotted-Line Recorder, set the following controls in the positions indicated:

1. CHART DRIVE lever (right) — N (neutral)
2. DRIVE UNIT — IDLE
3. CHART DRIVE switch — OFF
4. REF PLANE/VSWR — VSWR
5. VSWR % FULL SCALE — 20
6. INPUT SIGNAL LEVEL — 1 mV
7. CENTERING — 12 o'clock
8. Pen — Up

3.3 PRELIMINARY PROCEDURES.

Preliminary operating procedures are as follows:

a. Flip the Type 1521-SL power switch to POWER.

b. Terminate the slotted line with a Type 900-WO Open-Circuit Termination.

NOTE

In the following steps, adjust the power output of the source to keep the pointer of the SET LEVEL meter below the black wedge on the scale.

c. With the main carriage drive, position the probe for a maximum indication on the SET LEVEL meter at approximately 35 cm on the slotted line.

d. Adjust the stub of the probe-tuner for a peak indication on the SET LEVEL meter.

e. Adjust the 1-kc modulation setting on the signal source for a peak indication on the SET LEVEL meter.

f. Set the VSWR control to the desired scale expansion (refer to Table 3-1). Bring the pen to the center of the chart paper by adjustment of the power output of the source and by adjustment of the CENTERING control. The pointer should now be within the black wedge on the meter.

g. Rotate the DAMPING control slightly to damp jitter in the pen to within 0.1 to 0.2 of a minor division on the chart paper.

NOTE

Avoid overdamping. A slight residual jitter is desirable as evidence of full servo bandwidth.

h. Remove the Type 900-WO termination.

3.4 MEASUREMENT OF VSWR.

Recorded precision measurements below 1.200 of the VSWR of an unknown can be made as follows:

a. Attach the unknown to the load end of the slotted line (GR900 connector).

b. Select the appropriate setting of the VSWR % FULL SCALE control, if approximate prior infor-

TABLE 3-1

CHART PAPER CALIBRATIONS FOR CONVENIENT SETTINGS OF "VSWR % FULL SCALE" CONTROL

DIAL SETTING	*VSWR FULL SCALE*	*% VSWR MAJOR INTERVAL*	*% VSWR MINOR INTERVAL*	*|Γ| FULL SCALE*	*|Γ| MAJOR INTERVAL*	*|Γ| MINOR INTERVAL*
□ 0.8	1.008	0.100	0.020	0.004	0.0005	0.0001
▨ 1.0	1.010	0.100	0.020	0.005	0.0005	0.0001
□ 1.6	1.016	0.200	0.040	0.008	0.0010	0.0002
▨ 2.0	1.020	0.200	0.040	0.010	0.0010	0.0002
□ 4.0	1.040	0.500	0.100	0.020	0.0025	0.0005
▨ 5.0	1.050	0.500	0.100	0.025	0.0025	0.0005
□ 8.0	1.080	1.000	0.200	—	0.0050	0.0010
▨ 10.0	1.100	1.000	0.200	—	—	—
□ 16.0	1.160	2.000	0.400	—	—	—
▨ 20.0	1.200	2.000	0.400	—	—	—

|Γ| = Reflection coefficient magnitude
□ 40 division paper (P/N 1521-9428)
▨ 50 division paper (P/N 1521-9310)

TABLE 3-2

RECOMMENDED RECORDER CHART SPEEDS

SPROCKET	DIV/MIN SETTINGS			
	10 x 1	30 x 1	10 x 10	30 x 10
Large (0.5 cm/div)	Any freq.	Any freq.	Below 6 Gc/s	Below 2 Gc/s
Small (1 cm/div)	Any freq.	Any freq.	Below 3 Gc/s	Below 1 Gc/s

mation is available. Otherwise, set the control initially to 20 and gradually reduce the setting to get approximately ¾-full-scale magnification of the VSWR plot. If necessary, readjust the DAMPING control as in paragraph 3.3.

c. Adjust the CENTERING control and, if required, the power output of the source, to keep the pen on the chart paper.

d. Consult Table 3-2 to select the appropriate chart-drive speed and set the left-hand chart-lever at 10 or 30.

e. Move the carriage to the start of the desired probe travel with the control knob on the slotted line. Place the CHART DRIVE switch in the FWD position.

f. Throw the DRIVE UNIT control to NORMAL DRIVE.

g. Drop the pen gently on the chart paper.

h. Set the right-hand chart-drive lever to X1 or X10 (as appropriate from Table 3-2) and run the plot through at least two cycles of the standing-wave pattern. Then, return the lever to N to stop the carriage.

i. Lift the pen from the paper and throw the clutch control to IDLE.

j. Advance the paper with the MANUAL SET control until the plot clears the tear-gate. Pull one corner of the chart up and across the blade of the tear-gate to separate the chart cleanly.

3.5 COMPARISON MEASUREMENTS.

VSWR measurements of several unknowns, or repeated plots of the same unknown, may be run on the same strip of chart paper for comparison purposes. The procedure is the same as for normal VSWR measurements, with the following exceptions:

a. Use a VSWR % FULL SCALE setting that will permit:

1. Separate portions of the chart for each plot, if each is a measurement of very low VSWR.

2. On-scale plots of the highest-valued VSWR, if plots of widely varying VSWR's will be superimposed.

b. Lift the pen and set the CHART DRIVE switch to REV to reposition the probe at the same starting point for successive measurements.

c. Use the CENTERING control to place each plot in its assigned portion of chart paper. Drop the pen on the paper, reset the CHART DRIVE switch to FWD and repeat the process.

Multiple plots of low-VSWR unknowns can be combined on the same chart strip for direct comparison, as in Figure 3-3. A pair of GR900 connectors mounted on a half-wavelength section of air line and measured at six different radial orientations produced the plots shown. No conditions were changed between measurements; only the CENTERING control on the recorder was reset to place succeeding traces on separate portions of the chart paper.

The GR900 junctions at each end of the line were broken and the line was rotated so that the connector centering-gear rings were re-engaged at alternate intervals.

While this incidentally illustrates the VSWR repeatability of the GR900 connector, in both phase

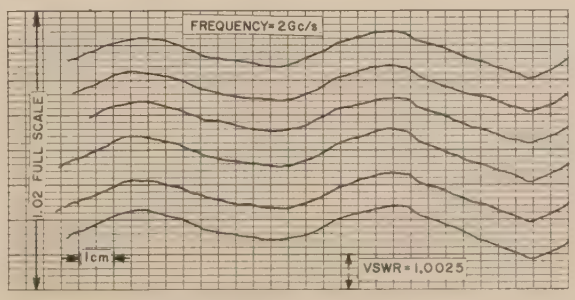


Figure 3-3. Multiple comparison measurements recorded on the Type 1640-A.

and magnitude, more importantly it suggests application to a multitude of two-port design situations. Connection-to-connection variations in VSWR magnitude within one minor division on the paper, or less than 1.0005, are easily discernible to within 1.0002.

3.6 MEASUREMENT OF REFERENCE PLANE.

The Type 1640-A system can be used to plot the positions of minima, with a short-circuit termination at the reference plane, on the same chart paper with the VSWR pattern of the unknown. This facilitates the measurement of the position-of-minimum of the unknown for Smith-chart plots of the measured data. The wavelength of the frequency to which the signal source is set is equal to the distance between similar portions of the first and third of three successive REF PLANE minima, relative to the horizontal scale, which is calibrated in cm (see Figure 3-4). The procedure is as follows:

a. Terminate the slotted line with the Type 900-WN Precision Short Circuit Termination supplied.

b. Place the REF PLANE/VSWR switch on the recorder in the REF PLANE position.

c. Operate the system as for VSWR measurements. There is no need to keep the pen movement on-scale, as the pen will alternately move from one limit of the scale to the other.

d. Return the REF PLANE/VSWR switch to the VSWR position.

e. Refer to paragraph 3.8 for measurement applications of the strip chart so obtained.

3.7 PRECISION WAVELENGTH MEASUREMENT.

The Type 1640-A can also be used to measure wavelength to 0.2-mm accuracy, but no strip-chart record can be made. The procedure is as follows;

a. Set up the system as in paragraph 3.4.

b. Place the CHART DRIVE control at OFF, the CHART DRIVE lever at N, and the DRIVE UNIT lever at IDLE.

c. Attach the Type 900-WN Precision Short-Circuit Termination to the slotted line.

d. Place the REF PLANE/VSWR switch in the REF PLANE position and the INPUT SIGNAL LEVEL control at 0.05 mV.

e. Position the carriage at a minimum, as indicated by a minimum on the SET LEVEL meter.

f. Record the probe position to within 0.1 mm.

g. Move the carriage to the second minimum beyond the original one and repeat the measurement of the position of the minimum. The distance between the two minima so measured is the wavelength at the frequency used.

For greater accuracy, repeat the measurement over several wavelengths.

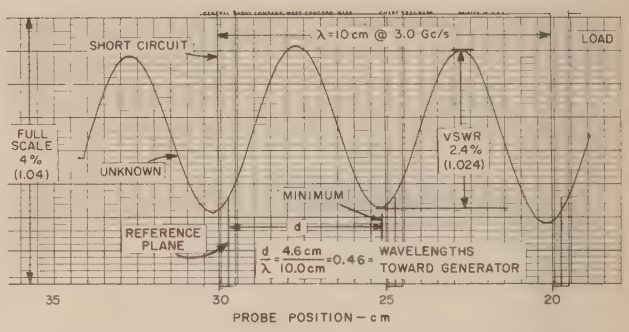


Figure 3-4. Typical chart record made by the Type 1640-A shows the positions of minima of an unknown with respect to a short circuit at the reference plane.

3.8 IMPEDANCE MEASUREMENTS.

Impedance measurements can be performed with the system by superposition of the standing-wave pattern of an unknown on a plot of the line as short-circuited with the Type 900-WN termination. The position of a minimum of the standing-wave pattern, with respect to an adjacent reference-plane point, determines a distance that, divided by the wavelength interval at the test frequency, yields the phase information of the unknown. The combined phase and magnitude information can then be applied to an expanded Smith chart to determine the impedance value.

The General Radio Smith chart, Form No. 5301-7562HE, offers a highly expanded, normalized paper useful with the system at VSWR scale expansions down to 4% full scale.

EXAMPLE: Figures 3-4 and 3-5 illustrate an impedance measurement performed by use of this technique. The strip chart plot of Figure 3-4 shows a typical unknown measured at 3.0 Gc/s with the VSWR % FULL SCALE control set at 4% and the paper scale set at 2 divisions per centimeter. The probe travel was from left to right, i.e., GENERATOR TO LOAD, over approximately 15 cm of the slotted line, terminated first with the "UNKNOWN" and then with the "SHORT-CIRCUIT."

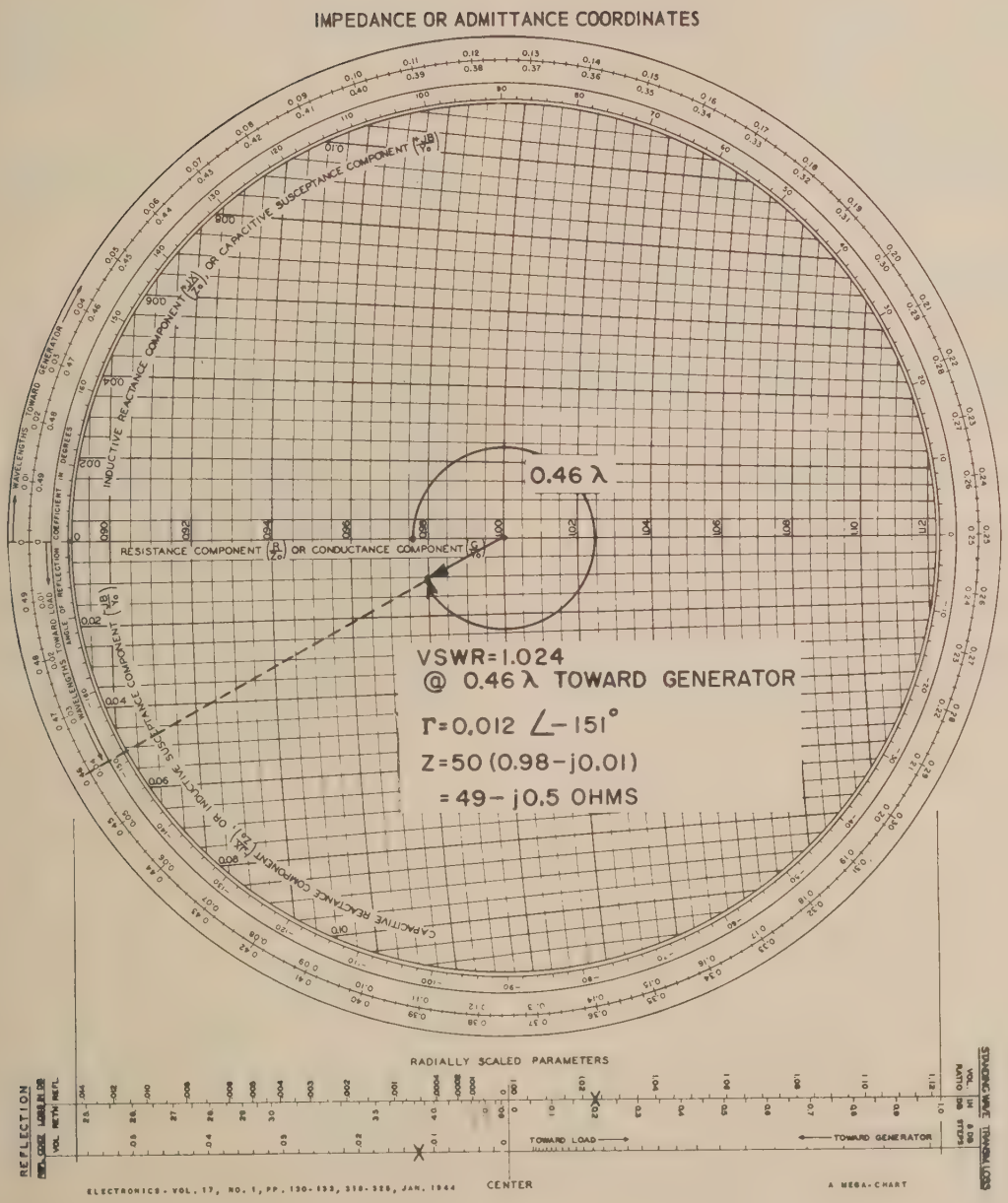


Figure 3-5. Impedance plot on highly expanded Smith chart of precision measurement data abstracted from strip-chart record of Figure 3-4.

The last full excursion of the standing-wave pattern was used to measure VSWR magnitude (1.024). The second minimum on the standing-wave pattern and the first minimum of the short-circuit pattern were used to determine "d," an interval of 4.6 cm. The interval divided by the 10-cm wave-length, d/λ, gives the corresponding Smith-chart rotation of 0.46 wavelengths. The minimum on the standing-wave pattern is taken as the starting point and a measurement can be made to either adjacent reference-plane minimum. In this example, the next minimum towards the generator was chosen. Thus, the phase information is applied to the "WAVELENGTHS TOWARD GENERATOR" scale on the Smith chart, Figure 3-5. A line from the center of the chart, intersecting the outer peripheral scale at 0.46, determines the angle of the phase line. The measured VSWR of 1.024, laid off on the "STANDING WAVE Vol. Ratio" scale and used to strike an arc on the phase line, establishes the normalized impedance coordinates, which can then be read from the Smith chart, $Z = 50(0.98 - j\,0.01)$.

3.9 SUBSTITUTION MEASUREMENTS.*

The Type 1640-A equipment can be used for precision substitution measurements made directly from the strip-chart plot, without resort to cumbersome vector manipulations to remove inherent system error from the measurement answer. This applies to both phase and magnitude measurement. Substitution measurements require only the difference in VSWR, between an "Initial Condition" and a "Final Condition." The difference is related to the VSWR of the unknown, and is most accurately read when the Initial Condition has a VSWR = 1.000.

The advantage of this technique over routine recorded VSWR measurements is that the accuracy that can be achieved is not limited to the accuracy of the slotted line, which varies with frequency from 0.1 to 1%. Instead, measurements accurate from 0.05 to 0.23% can be made over the frequency range of the system, i.e., 300 Mc/s to 9.0 Gc/s, if one of the Type 900-LZ Reference Air Lines is used as the standard.

Additional equipment required is a Type 900-W50 50-Ohm Standard Termination and a Type 900-TUA or -TUB precision coaxial tuner, which is needed to tune out the residuals in the system for the INITIAL CONDITION measurement. Typical applications of this technique are described in detail in the Special Measurement section of the Type 900-LB instruction manual.

*Type 900-LB Instruction Manual, paragraphs 4.2, 4.3, 5.3 and 5.4.

A.E.Sanderson, "Calibration Techniques for One- and Two-Port Devices Using Coaxial Reference Air Lines as Absolute Impedance Standards," ISA Conference, October 1964. Available as General Radio Reprint B-21.

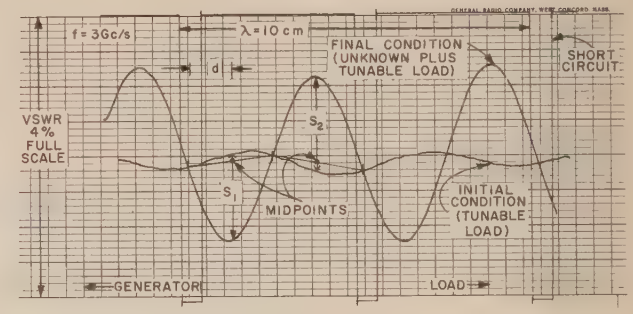


Figure 3-6. Typical half-wave substitution-measurement plot for a two-port unknown measured with a tunable load.

Figures 3-6 and 3-7 show the simple chart operations necessary for precision substitution measurements on any unknown within the VSWR range of the system. Note that the flatness effect of the line cancels out, so that the possibly misleading interpretations owing to deviations from perfect flatness are avoided. This leads to repeatable measurements of both phase and magnitude of VSWR's as low as 1.001.

First, the INITIAL CONDITION plot is run, with the tuner in the system, after the appropriate tuning screws have been set to remove the periodicity owing to reflections within the line itself and those of the 50-ohm termination.

This can be accomplished as a "dry run," with the paper drive disengaged and the excursions of the pen (in response to probe movement along the slotted line) observed to determine tuning convergence. Or, the tuner can be adjusted on successive plots until satisfactory flatness is achieved.

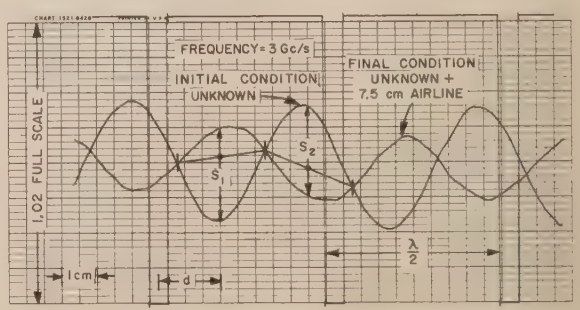


Figure 3-7. Typical quarterwave substitution measurement plot for a one-port unknown measured with a reference air line.

NOTE

A perfectly flat plot is not usually required, nor need the plot length exceed two wavelengths.

Then, change to the second configuration of the substitution measurement, and run the plot marked FINAL CONDITION starting at the same point as the the first plot.

If VSWR-magnitude information is all that is required, these two plots are sufficient. If phase information is also required, replace the unknown with the Type 900-WN Short-Circuit Termination, return the paper to the same starting point, and run the plot marked SHORT CIRCUIT.

Remove the strip chart and draw two straight lines, each connecting a pair of cross-over points between the initial and final plots.

Find the midpoints of each of the lines and project a vertical, up or down, as the case may be, to the initial plot. Mark the point of intersection. Continue the projections and mark the points of intersection with the final plot. The intervals between the two pairs of points so determined are marked S_1 and S_2.

Measure S_1 and S_2, in terms of the scale expansion used, and add the values so determined to obtain the VSWR magnitude of the unknown.

An additional interval, d, projected from line S_1, to the midpoint of the short-circuit minimum, is an accurate measure of the position of minimum of the unknown with respect to the reference plane, and can be applied for impedance measurements, as in paragraph 3.8.

EXAMPLE: The measurement shown in Figure 3-6 was performed on a low-VSWR two-port unknown fitted with GR900 connectors. Since any termination residual would add to or subtract from the VSWR of the unknown, a tunable load was used, consisting of a Type 900-TUA Tuner ahead of a Type 900-W50 50-Ohm Termination. The measurement system was tuned flat and the INITIAL CONDITION plot was run with virtually all VSWR-error contributions of every element of the system tuned out.

Then, the unknown ($\lambda/2$ wavelength long at 3 Gc/s) was inserted between the tunable load and the slotted line and the FINAL CONDITION plot was run. The sum of the values read from the constructions of S_1 and S_2 (at the midpoints of the line segments joining two adjacent crossings of the plots) yield the VSWR of the unknown, unaffected by the VSWR of the slotted line and load. Thus:

$$VSWR = 1 + S_1 + S_2 = 1 + 0.0125 + 0.0135 = 1.026$$

For an impedance or reflection-coefficient measurement at the input of the unknown, the Type 900-WN Short Circuit Termination was placed at the reference plane of the slotted line, and the SHORT CIRCUIT plot was run. The interval, d, between the midpoint of the REF PLANE minimum and the first minimum of the VSWR plot at S_1 indicates 0.12 wavelengths on the WAVELENGTHS TOWARD GENERATOR scale of a Smith chart.

Yet another example of the substitution method is illustrated in Figure 3-7. Here, the quarter-wave technique was used to separate the extremely low VSWR of a one-port unknown from the residual VSWR of the measurement system. The plot labeled INITIAL CONDITION was run with a GR900 equipped one-port unknown connected directly to the slotted line. Then, a second plot (FINAL CONDITION) was run with a Type 900-LZ7H Reference Air Line ($3\lambda/4$ wavelength at 3 Gc/s) inserted ahead of the unknown. Midpoints between two adjacent crossings of the plots were determined and the verticals S_1 and S_2 projected. The value of the unknown is here one-half the sum of S_1 and S_2 because of the impedance-inversion property of the quarter-wave line. The interval d was determined as above. The VSWR of the unknown is 1.0064 and $\frac{d}{\lambda}$ is 0.18 wavelength toward generator.

3.10 STRIP-CHART DIAGNOSIS.

3.10.1 GENERAL.

The Type 1640-A Recorder strip-chart output can be reliably used to monitor the system. As an aid to rapid evaluation of system performance, a series of sample charts appears in Figures 3-8 through 3-10. They show the typical output of a properly functioning system corresponding to various representative values of the three paramount variables in system operation — frequency, VSWR-scale expansion, and input-signal level. Every chart in each series contains a plot of an arbitrary unknown, a plot of line flatness at a given combination of control settings, and a plot with the slotted line short-circuited by the Type 900-WN termination.

System performance should closely resemble the appearance of the samples, under the same conditions. If not, suitable allowance must be made in the determination of final measurement values. Refer to Section 4 for procedures to check the calibration of the system. Refer to Section 6 for procedures to correct recorder operation, and to the Type 900-LB instruction manual to correct slotted-line operation.

First, ascertain that the faulty indication is not the result of improper operation of the system (refer to paragraph 3.10.2) and that the signal source is performing properly, as described in paragraph 3.10.3.

For the most part, these chart samples were taken with a VSWR-scale expansion of 4%, a representative setting. The mismatch of the load for each VSWR plot was individually adjusted to occupy just over half the chart scale. Except where otherwise indicated, the INPUT SIGNAL LEVEL setting was 1.0 mV.

In Figure 3-8, where the VSWR % FULL SCALE control was set at key points throughout its range, note that the VSWR plot at 0.8% is almost as good as it is at 16% full scale and that in either condition the waveform is clean and noise-free.

Note also in the charts of Figure 3-8 that the flatness appears to deterioriate at greater expansion, i.e., towards 0.8%, but that the actual reading remains a constant 1.003.

Figure 3-9 shows typical performance as a function of frequency; note the reduction of wavelength and compression of the standing-wave pattern with increasing frequency. This effect is minimized by the choice of the drive sprocket. Consequently, the smaller (1 cm/div) sprocket is recommended at frequencies below 1 Gc/s and the larger (0.5 cm/div) sprocket above 1 Gc/s. The pattern compression necessitates slower chart speeds at high frequencies, for the plot to remain within the servo bandwidth of the recorder (Table 3-2). Time to record a standing-wave pattern is practically independent of the test frequency, since the recommended chart speed is roughly inversely proportional to frequency, and two cycles of the standing-wave pattern are usually sufficient.

Record the standing-wave pattern of the flattest portion of the line at each frequency, to minimize the effects of non-constant probe pickup. Select the flattest portion from a full-length flatness plot made at the test frequency (e.g. the portion between 35 and 50 cm in Figure 4-8). A substantial improvement of flatness over specifications is always possible over a restricted section of the slotted line.

The adjustment of the tunable load required for a flatness curve need not be carried to extremes. A residual VSWR pattern (of up to 1 major division) included

FIXED CONDITIONS

FREQUENCY — 3.0 Gc/s
PROBE TRAVEL — 0.5 cm/div
INPUT SIGNAL LEVEL — 1 mV
CHART SPEEDS —
VSWR = 100 DIV/MIN
FLATNESS = 30 DIV/MIN
REF PLANE = 30 DIV/MIN

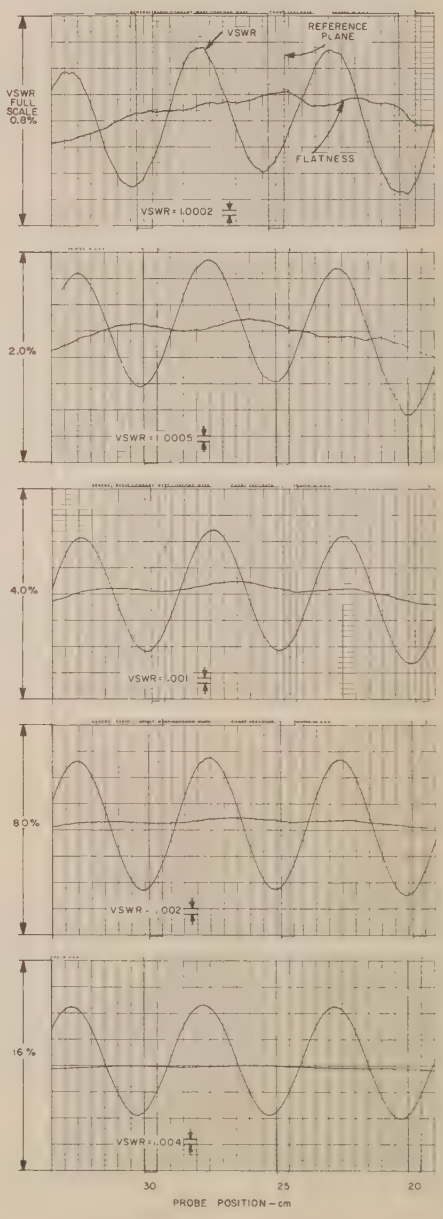
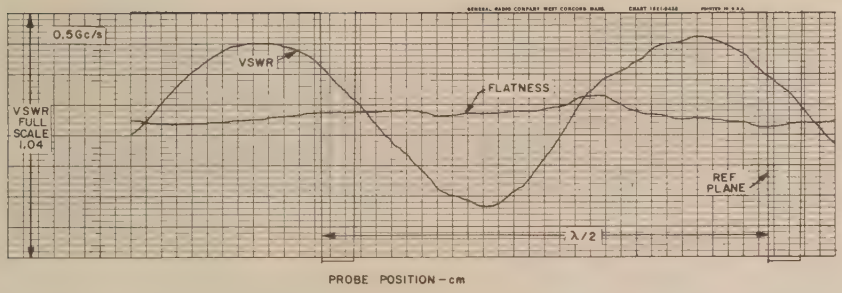
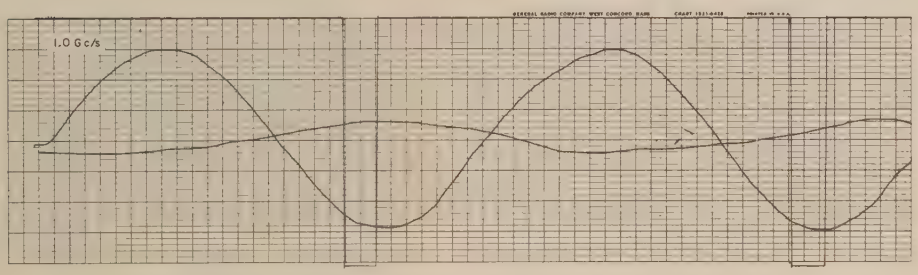
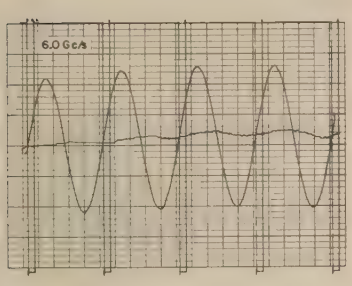
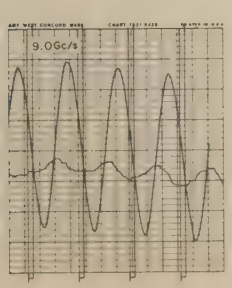


Figure 3-8. Typical chart records obtained at 3.0 Gc/s for various settings of the VSWR % FULL SCALE control.









FIXED CONDITIONS

PROBE TRAVEL — 0.5 cm/div
(except 1 cm/div at 0.5 Gc/s)
VSWR % FULL SCALE — 4%
INPUT SIGNAL LEVEL — 1 mV

PLOT	*FREQ-Gc/s*	*CHART SPEED*
VSWR	0.5	100 DIV/MIN
FLAT.	&	100 DIV/MIN
REF PLANE	1.0	30 DIV/MIN
VSWR	6.0	30 DIV/MIN
FLAT.	&	30 DIV/MIN
REF PLANE	9.0	10 DIV/MIN

Figure 3-9. Typical chart records obtained at a VSWR FULL SCALE control setting of 4% (equivalent VSWR of 1.04) at representative test frequencies.

with the flatness curve will not usually interfere with proper determination of the phase and magnitude of the unknown standing-wave pattern in a substitution measurement, as can be seen in the 1- and 9-Gc curves of Figure 3-9. The only exception would be measurement of the slotted line itself. A substitution measurement is illustrated in Figure 3-6.

The short-circuit REF PLANE marks are also compressed as the frequency is increased, but the position of the reference plane is always midway between the two sides of the null, at any frequency.

The chart series of Figure 3-10 illustrates the effects of various settings of the INPUT SIGNAL LEVEL control, with all other conditions (including a load of VSWR≈1.030) held constant.

The chart marked "USUAL SETTING 1 mV" is the standard. Those above demonstrate the increased noise content in plots made at low signal levels and the one below it demonstrates the magnitude distortion of measured VSWR that can set in. Note, however, that the phase of the plot is unaffected, as indicated by the constancy of the positions of minima with respect to the REF PLANE traces.

For settings above 1 mV, the VSWR is on the low side by approximately 5%. For settings below 1 mV, the VSWR plot is constant in magnitude but the noise content increases in severity at each lower setting. The noise-level error is much more apparent in the FLATNESS measurements, and is equivalent to a VSWR≈ 1.001 at the usual setting and to a VSWR≈1.003 at the 0.05-mV setting, as the S/N ratio of the recorder diminishes.

Consequently, INPUT SIGNAL LEVEL settings outside the range of 0.3 to 1.0 mV are to be avoided, except in special circumstances (for example, to permit use of weak signal sources or to improve the S/N ratio in the measurement of very low VSWR).

3.10.2 INDICATIONS OF IMPROPER OPERATION.

A very likely cause of misleading strip-chart indications is the use of improper chart-drive speeds. If speeds greater than those recommended in Table 3-2 are used, the accuracy of both magnitude and phase measurements will be affected at test frequencies above 1 Gc/s. The distortion is due to the failure of the servomechanism to follow accurately when the frequency of the sine-wave VSWR pattern exceeds the servo bandwidth of the recorder.

Figure 3-11 shows comparison plots of two measurements of the same unknown made at 9.0 Gc/s, both at a 4% VSWR scale expansion, but at different paper-drive speeds.

FIXED CONDITIONS

FREQUENCY — 3.0 Gc/s
PROBE TRAVEL — 0.5 cm/div
VSWR FULL SCALE — 4%
LOAD VSWR = 1.030
CHART SPEED —
VSWR = 100 DIV/MIN
FLATNESS = 30 DIV/MIN
REF PLANE = 30 DIV/MIN

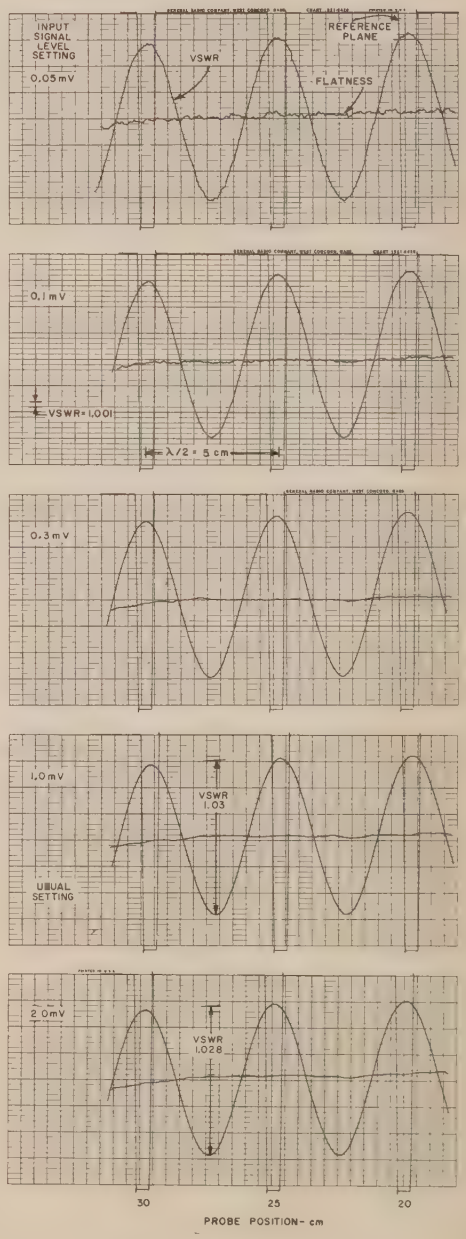


Figure 3-10. Typical chart records obtained at 3.0 Gc/s (with a VSWR FULL SCALE control setting of 4%) in response to various settings of the INPUT SIGNAL LEVEL control.

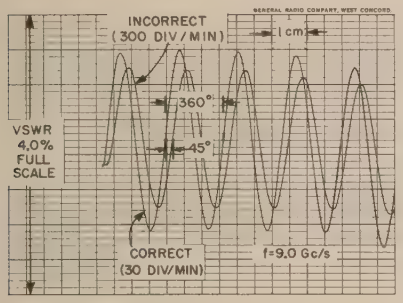


Figure 3-11. Comparative plots of the same unknown to show the distortion that results in the strip chart record if the CHART DRIVE speed setting is too high. The test frequency is 9.0 Gc/s and the VSWR FULL SCALE control set for 4%.

Observe that the plot marked "INCORRECT" distorts the amplitude indication, reducing it to approximately 77% of the correct value. At the same time, the phase has been shifted approximately 45°. Both distortions have been caused by operation at ten times the recommended chart speed. Bear in mind that distortions of this type can have an insidious effect on measurement accuracy, since there is no obviously improper indication.

However, plots of the line short-circuited have a more obvious distortion when they are run at too high a speed, as shown in Figure 3-12. These plots were made at successively higher chart speeds (at 9.0 Gc/s). The pairs of minima plotted at 10 and 30 DIV/MIN are both correct, but at 100 DIV/MIN distortion sets in and at 300 DIV/MIN the distortion is an obvious indication of improper operation.

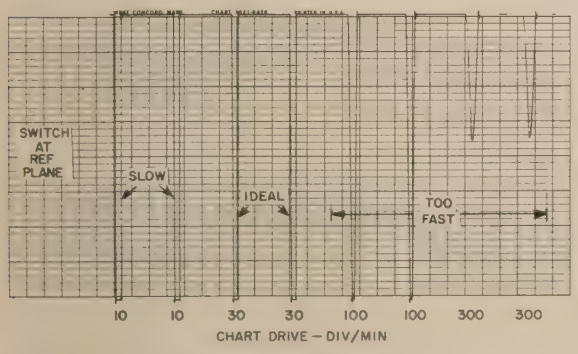


Figure 3-12. REF PLANE plots on strip chart made at 9.0 Gc/s at four CHART DRIVE settings; the 30 DIV/MIN rate is contrasted with higher and lower speeds. While the 10 DIV/MIN rate does not distort the plot, as with the higher speeds, it is an inefficient use of machine time.

3.10.3 SIGNAL-SOURCE AMPLITUDE STABILITY.

For maximum accuracy, the signal source must exhibit an amplitude stability smaller than 0.02% rms. Otherwise, measurement accuracy of small VSWR can be noticeably affected.

As a preliminary check on a new source, or as an occasional routine check, it is advisable to use the recorder system to observe the short-term amplitude stability of the source. The chart of Figure 3-13 shows the typical performance of the General Radio Type 1360-B Microwave Oscillator, operated at 3.0 Gc/s. For this test, the probe drive is declutched (drive unit set at IDLE) and the CHART DRIVE set for 30 DIV/MIN. The sample shown demonstrates the

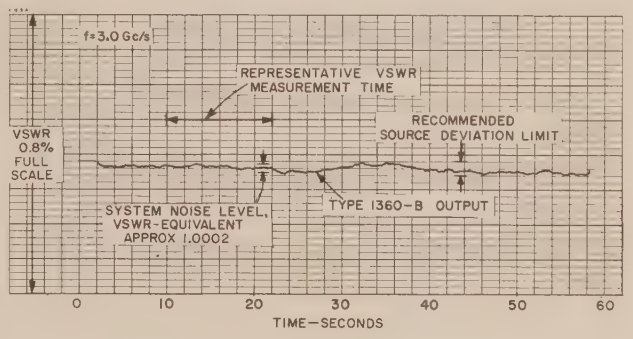


Figure 3-13. Use of strip chart record to determine the short-term amplitude stability of the Type 1640-A system, including the external signal source, crystal detector, and recorder. This plot was made at a test frequency of 3.0 Gc/s with the VSWR FULL SCALE control set at 0.8% and the CHART DRIVE set for 30 DIV/MIN. The slotted-line probe remained in one position throughout. Note the small amount of system noise on the plot, even at maximum scale expansion.

stability of this source over a 50-second interval. The plot is bracketed by the limits of permissible deviation.

An unstable source can distort the strip-chart plot, making the sine-wave VSWR pattern appear noisy. This, of course, leads to difficulty in chart interpretation with consequently less accurate results than should be obtained.

Frequency instability and instability of the 1-kc modulator in the source will show up in the same manner as amplitude instability.

A noisy diode in the slotted line can also give the same symptoms (refer to paragraph 3.10.5).

3.10.4 SIGNAL-SOURCE FREQUENCY CHECK.

Much greater accuracy in frequency setting can be accomplished with controls and indicators on the slotted-line recorder system than can be looked for from the dial indication of the usual commercially available signal source (i.e. 1%).

The system's superior capability in this regard stems from the high repeatability of the GR900-connector reference plane and from the fact that the slotted-line carriage-position scale, which is calibrated with this reference plane as 0 cm, is accurate to ±(0.1 mm + 0.05%).

Thus, to set frequencies to 0.1% accuracy, and to be able to repeat frequencies for substitution measurements taken at different times, the following procedures are suggested:

a. Connect the signal source in the usual way, set it to the desired frequency according to the dial calibration, and terminate the slotted line with the Type 900-WN short circuit.

b. Set the recorder for REF PLANE operation and the INPUT SIGNAL LEVEL control fully CCW.

c. Move the probe into a minimum, as indicated on the SET LEVEL meter, near the left-hand (62 cm) end of the slotted line.

d. Resonate the probe-tuner assembly for a peak indication at this position.

e. Calculate the half-wavelength interval at the frequency (to 0.1-mm precision if desired) and set the carriage at an integral multiple of this interval.

f. Adjust the *oscillator* frequency control slightly for a sharp, deep null on the SET LEVEL meter.

3.10.5 DETECTOR DIODE DEFECTS.

The quality of the diode detector mounted in the slotted-line portion of the system can have a direct effect on measurement accuracy. The diode can deteriorate in time, as a result of rough handling, and become "noisy." Consequently, as shown in Figure 3-14, it can reduce system resolution by 50% or more. The two comparative plots were made at a maximum scale expansion, over approximately a 50-second interval, with the chart drive decoupled from the slotted-line carriage (no probe movement). The load conditions were the same for both plots.

To illustrate the effect, if a 10-second measurement interval is taken as typical, the good diode output varies in its worst case (between 20 and 30 seconds) within 2 minor divisions. The VSWR equivalent of this noise is 1.0004. Over most of the plot the noise variation is within 1.0002.

By way of contrast, the lower plot exhibits a noise variation of 1.0006, or greater, throughout its length. Thus, if chart records consistently fail to display the clean plots typical of Figures 3-8 through 3-10, plots should be run with several diodes, as demonstrated in Figure 3-14, to evaluate the diode type in use. If all perform outside the limits, the trouble may be due to signal-source instability; refer to paragraphs 3.10.3 and 3.10.4.

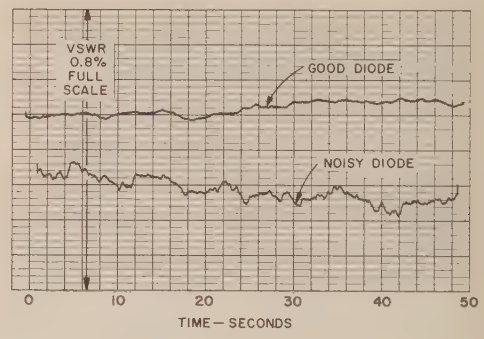


Figure 3-14. Contrasting plots that demonstrate the resolution reduction that can be caused by a noisy diode in the slotted-line detector.

3.10.6 DAMPING-CONTROL ADJUSTMENTS.

Improper setting of the DAMPING control on the recorder can affect the accuracy of both phase and magnitude measurements. Figure 3-15 shows repeated measurements performed under the same test conditions at four different settings of the DAMPING control.

The measurements were made at 3 Gc/s with a VSWR FULL SCALE setting of 4%, an INPUT SIGNAL LEVEL setting of 1 mV, and the line terminated in a load of VSWR approximately equal to 1.015.

The bottom plot, run with the control fully CCW, displays excessive pen jitter corresponding to an under-

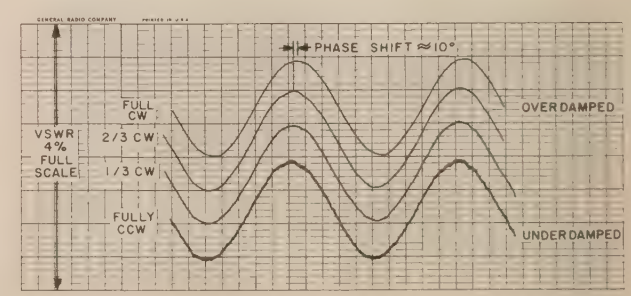


Figure 3-15. Plots illustrating the effect of various DAMPING control settings for repeated measurements at 3 Gc/s on a load with a VSWR of 1.015.

damped condition. Note that the width of the trace approaches one minor division on the chart paper with consequent reduction in the resolution capability of the system.

The next trace above was run with the control rotated 1/3 CW and indicates one bound of the normal setting limits. It exhibits a very minor trace widening but is undistorted.

The trace above that was run with the control rotated an additional 1/3 turn CW and indicates the other bound of the normal setting limits. It is a trifle underdamped, but undistorted.

The top trace was run with the control fully CW. It is a smooth regular trace hardly distinguishable from the two correct traces beneath it in amplitude and waveform. However, notice that the peak is shifted to the right of the peak in the other traces. This constitutes a phase shift of approximately 10 degrees.

A properly operating system should be able to produce a trace falling between the two center traces in Figure 3-15, under the same test conditions.

The proper setting of the DAMPING control depends somewhat on the setting of the VSWR % FULL SCALE control. A large scale change will necessitate a slight readjustment of the DAMPING control.

SECTION **4**

SYSTEM CALIBRATION AND SPECIAL MEASUREMENTS

4.1 GENERAL.

This section contains information pertaining to the calibration of the Type 1640-A Slotted Line Recorder System and system application to special measurements.

4.2 SYSTEM CALIBRATION.

4.2.1 GENERAL.

Information on procedures and equipment needed to ascertain that the Type 1640-A Slotted Line Recorder System is capable of performance within specified accuracy appears below. Material covered pertains to the system internal standard, namely the Type 900-LB Precision Slotted Line. In particular, it is concerned with the method for determination of the two electrical characteristics that most directly reveal the accuracy of that instrument. . . residual VSWR and "flatness." For calibration of the Type 1521-SL Recorder, refer to Section 6.

NOTE

As supplied, the system is warranted to perform within stated specifications, so that the usual measurement procedures of Section 3 require no preliminary calibration. What follows is required only if the slotted line has been subjected to possibly damaging stresses or has been disassembled.

4.2.2 RESIDUAL VSWR CALIBRATION.

The theory underlying the calibration technique is fully explained in Section 5 of the instruction manual for the Type 900-LB Slotted Line. A brief, descriptive resume appears below.

The accuracy of any measurement system depends ultimately upon the degree of refinement with which it can be calibrated; this, in turn, depends upon the availability of precise, stable standards. For precision slotted-line equipments, this means standards with an inherent error below the already low residual of the line (0.1 - 1.0%).

4.2.3 AIR-LINE STANDARDS (Figure 4-1).

The Type 900-LZ Reference Air Lines, which possess VSWR specification of $1.0005 + 0.0002 \times f_{Gc}$, comprise a set of external standards for calibration of the Type 900-LB slotted line. These are sections of coaxial transmission line dependent (as electrical standards) only upon the dimensional accuracy of their precision-machined inner- and outer-conductor diameters. To provide the ultimate in 50-ohm impedance standards, these lines avoid even the minor dis-

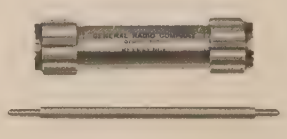


Figure 4-1. Type 900-LZ Reference Air Line (typical) with inner conductor shown in foreground.

continuities caused by an optimally designed support bead. By a novel adaptation of the GR900 coupling system, the center conductor takes its support instead from the GR900 connectors of the devices with which it is mated. The lines, which come in six lengths, furnish many well distributed calibration points throughout the frequency range of the system.

For accurate calibration, it is also necessary to have a termination of VSWR equal to that of the slotted line. The Type 900-TUA Tuner, a versatile and unique coaxial screw-type tuner, together with the Type 900-W50 50-Ohm Termination, constitutes a tunable termination that can be made equal to the slotted line in VSWR and of opposite phase to permit calibration at maximum scale expansion on the recorder.

Since instrument and termination errors tend to be indistinguishable at these low levels, a means to separate them is required. The reference air line, inserted between the slotted line and the composite termination, offers just such a means. The separation is accomplished by the phase reversal made possible, at odd-quarter-wavelength intervals, by insertion of the lines in the calibration setup.

With a full complement of these calibration devices, measurements can be performed at 31 frequencies throughout the range of the system. Table 4-1 lists the calibration frequencies and Figure 4-2 shows VSWR performance of the lines.

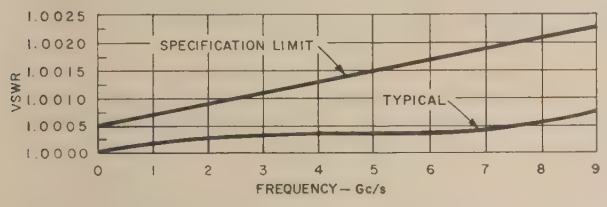


Figure 4-2. VSWR performance of Type 900-LZ Reference Air Lines (all six).

4.2.4 TUNER.

The Type 900-TUA and -TUB Tuners are useful to match out residual reflections of rf terminations at frequencies between 0.25 and 9 Gc/s. These tuners comprise a section of nominally 50-ohm coaxial transmission line with three adjustable tuning screws located asymmetrically along the line. The screws can be adjusted in and out with respect to a "neutral" position. Only two screws are adjusted at any given frequency. The third screw is left in the neutral position, which is 5.00 on the scales. Input and output connectors are Type 900-BT.

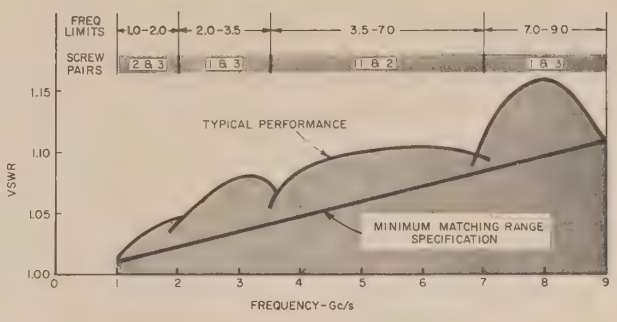


Figure 4-3. VSWR matching range of Type 900-TUA Tuner.

The tuning range of the Type 900-TUA Tuner is dependent on the phase of the reflection to be tuned out, relative to the location of the tuner in the test transmission line, and on the frequency of operation. The largest VSWR that can be tuned out under all conditions of mismatch, phase, and frequency is $1.00 + 0.012 \times f_{Gc}$ (see Figure 4-3).

The Type 900-TUB covers the frequency range of 0.25 to 2.5 Gc/s.

The locations of the tuning screws and their locks are shown in Figure 4-4; the screws to be adjusted as a function of frequency are tabulated on the tuner. The locks, if partially made, permit friction driving of the tuning screws. If fully made, the locks provide long-term stability of adjustment and protection against accidental movement. The tuning screws have engraved scales reading from 1 to 8 with a 0.1 least count.

4.2.5 TYPE 900-W50 TERMINATION.

The Type 900-W50 50-Ohm Termination (Figure 4-4) is a broadband, low-VSWR device with a frequency range from dc to 9 Gc/s. It comprises an accurately

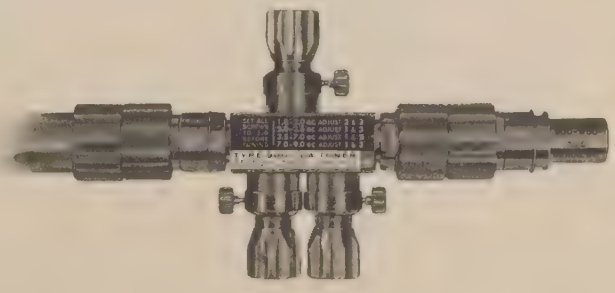


Figure 4-4. GR900 tunable load attached to Type 900-LZ Reference Air Line for calibration purposes.

TABLE 4-1
QUARTERWAVE-LENGTH FREQUENCIES FOR TYPE 900-LZ REFERENCE AIR LINES

FREQ Gc/s	*ODD-QUARTERWAVE MULTIPLES*					
	LZ5 (5 cm)	*LZ6 (6 cm)*	*LZ7H (7.5 cm)*	*LZ10 (10 cm)*	*LZ15 (15 cm)*	*LZ30 (30 cm)*
0.25						1
0.50					1	
0.75				1		3
1.00			1			
1.25		1				5
1.50	1				3	
1.75						7
2.25				3		9
2.50					5	
2.75						11
3.00			3			
3.25						13
3.50					7	
3.75		3		5		15
4.25						17
4.50	3				9	
4.75						19
5.00			5			
5.25				7		21
5.50					11	
5.75						23
6.25		5				25
6.50					13	
6.75				9		27
7.00			7			
7.25						29
7.50	5				15	
7.75						31
8.25				11		33
8.50					17	
8.75		7				35
9.00			9			

derived, continuous transition and a precision cylindrical 50-ohm resistor; the connector is a Type 900-BT. Typical VSWR characteristics are given in Figure 4-5. The change of resistance and VSWR vs heating due to incident power is negligible up to 1 watt.

4.2.6 PROCEDURES — RESIDUAL VSWR.

The calibration procedures are:

a. Arrange the equipment as indicated in Section 2 and adjust it as in Section 3, set the recorder controls as follows:

VSWR % FULL SCALE — 4.
REF PLANE/VSWR — VSWR.
INPUT SIGNAL LEVEL — 1 mV.

b. Set the source carefully to the appropriate frequency and set probe depth to 0.100 and probe tuner to resonance (as indicated in paragraph 3.2.4).

c. Attach the Type 900-W50 Termination to the right-hand port of the Type 900-TUA Tuner, to form a tunable load.

d. Attach the assembly to the GR900 connector of the slotted line.

e. Set all three screws on the tuner to 5.0 (neutral) and lock the screw, as indicated on the tuner nameplate, that is to remain at 5.0.

f. Run several plots that represent probe travel along at least a half-wavelength portion of the slotted line. Between plots, alter the settings of the active tuning screws to reduce the periodicity of each succeeding plot. (Refer to paragraphs 4.2.7 and 4.2.8 for details.)

NOTE

If the mismatch is outside the matching range of the tuner, either the slotted line or the termination is outside specification. The termination can be checked by the method of paragraph 3.9. If the termination is all right, then the slotted line may have been damaged, and the service section of the Type 900-LB Operating Instructions should be consulted.

g. Change the VSWR % FULL SCALE setting to 0.8 and continue the process slowly and carefully, until the plot is as flat as possible (VSWR $\cong$ 1.000).

h. Rerun the last plot in the center of a fresh section of chart paper, as in Figure 4-6.

i. Remove the tunable load and install the appropriate Type 900-LZ Reference Air Line (e.g., at 3.0 Gc/s, use the Type 900-LZ7H air line at $3\lambda/4$) between it and the slotted line.

j. Run a plot superimposed on the TUNABLE LOAD (VSWR $\cong$ 1.000) plot.

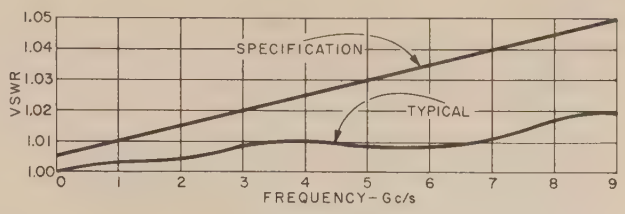


Figure 4-5. VSWR performance for Type 900-W50.

k. Measure the VSWR difference between the two plots at the midpoints between several successive crossings.

l. Average an even number of these VSWR values to determine the magnitude of the residual VSWR of the slotted line.

NOTE

The accuracy of the result depends directly upon the accuracy with which the initial flattening operation is carried out, so care must be exercised in this adjustment.

m. Compare this VSWR value with that indicated on the Type 900-LB residual VSWR specification curve. If it is within specification, system accuracy is as it should be. If not, consult the service section of the Type 900-LB instruction manual.

In Figure 4-6,

$$\text{VSWR} = 1 + \frac{S_1 + S_2 + S_3 + S_4}{4}$$

$$= 1 + \frac{0.0020 + 0.0018 + 0.0021 + 0.0022}{4}$$

$$= 1.0020$$

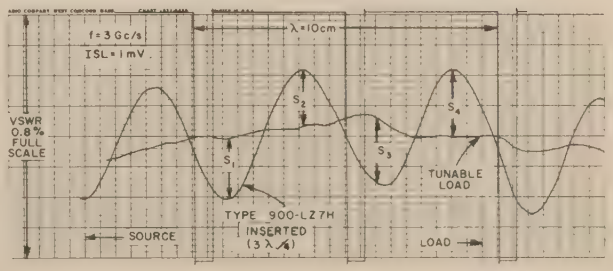


Figure 4-6. Substitution-method calibration plot for Type 900-LB slotted line. The matched load is a Type 900-W50 Termination plus Type 900-TUA Tuner tuned flat.

n. If the phase of the standing-wave pattern is also of importance, as it is for a Smith-chart plot of the slotted-line error, determine d/λ for use on the WAVELENGTHS TOWARD GENERATOR scale of the Smith chart (refer to paragraph 3.8). Correction of measured data for slotted-line error (required only in nonsubstitution measurements) is covered in paragraph 5.5 of the Type 900-LB Operating Instructions.

4.2.7 TUNER CONVERGENCE TO MATCH.

The following is a detailed example of the tuning process called for in paragraph 4.2.6 to flatten the coaxial-line measurement system. The series of sample chart runs that appears in Figure 4-7 illustrates the method of convergence to match. The samples were run at a test frequency of 3.0 Gc/s with the recorder VSWR % FULL SCALE control set at 4 and the INPUT SIGNAL LEVEL set at 1 mV.

With the same equipment setup as in paragraph 4.2.6, a plot was run (as in chart A) with all three screws of the Type 900-TUA Tuner set at 5.0.

With the drive clutch engaged, but with the pen lifted, the probe was moved back to a minimum. Tentatively, the two active tuning screws were adjusted to see which resulted in greater pen deflection to the left. Since the samples were run at 3 Gc/s, screws 1 and 3 were adjusted. In this example, screw 1 exhibited the greater effect. It was adjusted and plots were run as shown in successive traces; screw 3 was first returned to 5.0. The top plot (with screw 1 at 4.1) exhibited flattening and showed phase shift approaching 90°. This was about the maximum subtractive-reactance effect that could be accomplished with this screw, and a change to the other screw was in order.

NOTE

In the convergence process, change in phase of successive plots is a more sensitive indicator than changes in amplitude.

The top trace of chart A was repeated at the bottom of chart B, with tuning screw 3 still at 5.0. Then, screw 3 was turned in the appropriate direction (to 5.1 to add reactance) and a new, quite flat plot was run.

Then, to verify convergence, screw 3 was overadjusted (to 5.2), and a plot was run which is periodic, like the bottom trace, but out of phase with it. Thus, it is obvious that a setting around 5.1 was desired. However, as the trace at 5.1 exhibited slight periodicity and phase shift relative to the initial trace, a setting at 5.09 was tried. The result shown at the top of chart B is a nearly aperiodic trace which, over two half-wavelengths (10 cm at 3 Gc/s), gives a residual VSWR of the measuring system of approximately 1.001, adequate for 0.1% accuracy and sufficient for most precision work.

4.2.8 ULTIMATE MATCHING.

Should even greater precision than that of paragraph 4.2.7 be required, the recorder should be set for a VSWR % FULL SCALE of 0.8 and repeat traces should be run, as shown in chart C of Figure 4-7.

This is particularly necessary in the calibration of a Type 900-LB Precision Slotted Line. Here the chart was advanced to a fresh section and the last

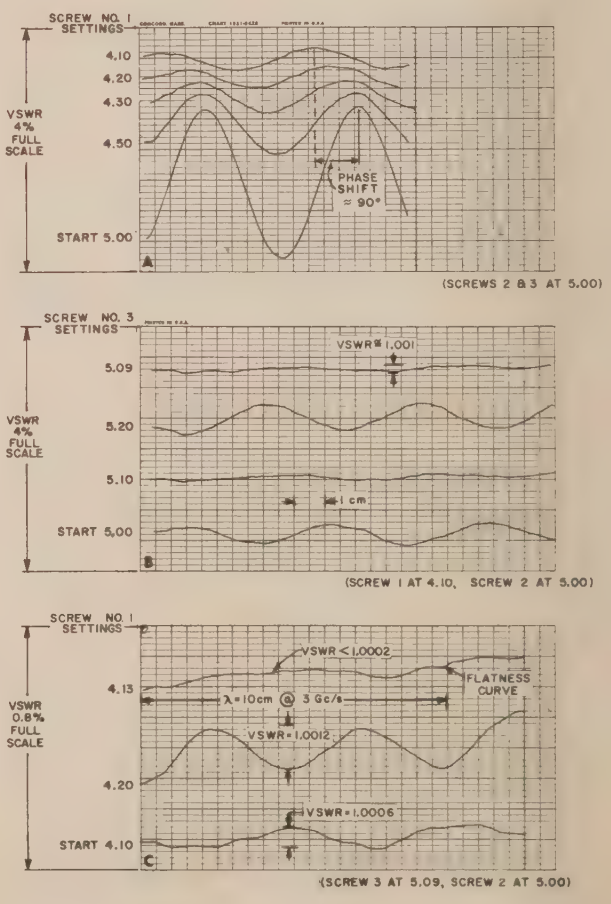


Figure 4-7. Type 1640-A plots showing convergence of matching process achieved with Type 900-TUA Tuner as part of the tunable termination.

run of chart B (paragraph 4.2.7) was replotted. The CENTERING control was used to move the plot to the lower edge of the paper.

The alternate screw (screw 1) was then set to 4.20, an arbitrary overadjustment for contrast, and a new plot run. From this it can be seen that a 0.1 turn of the tuning-screw thimble increased the mismatch by a factor of two and reversed its phase. The correct value (4.13) was interpolated from the previous two measurements, to obtain the final setting. Thus, the system was flattened to within a residual VSWR of 1.0002.

4.2.9 LINE FLATNESS.

A second factor that can affect system accuracy is the flatness of the slotted line, that is, the constancy of rf voltage picked up by the probe along the entire length of the slot. If it exceeds the specified value of ±0.5%, it can cause error in chart interpretation, particularly at the lower frequencies.

At frequencies where the line is several half-wavelengths long, choose the flattest section of the line for VSWR recordings, as a substantial improvement over specification is always possible by this means. For instance, in Figure 4-8, note that the plot is flat to within ±0.1% between 35 and 50 cm. For work at frequencies above 1 Gc/s ($\lambda/2$ = 15 cm), this portion of line should be preferred. Incidentally note that flatness over this region exceeds specified performance by a factor of 5.

4.2.10 PROCEDURE — FLATNESS.

The procedure for the flatness calibration is as follows:

a. Tune the transmission-line system to, or as close as possible to, a VSWR of 1.000, as indicated in the procedure of paragraphs 4.2.7 and 4.2.8.

b. Run a plot the entire length of the slotted line, as shown in Figure 4-8.

c. Compare the actual variations in probe voltage pickup with the specified value of ±0.5%, to see if the actual plot is within specification.

d. If not, check for generator stability, as described in paragraph 2.3, and crystal noise, as described in paragraph 3.10.4.

e. If generator stability and crystal noise level are both satisfactory, and the line does not meet the flatness specification, consult the service section of the Type 900-LB instruction manual.

4.3 SPECIAL MEASUREMENTS.

4.3.1 PRECISION REFLECTION-COEFFICIENT MEASUREMENTS > 0.1 (VSWR > 1.2).

While primarily designed for precise measurements of VSWR below 1.2, the Type 1640-A Slotted Line Recorder System can be adapted for precise measurements of reflection coefficient. A few relatively inexpensive General Radio instruments and devices, arranged in conjunction with the system, are the only accessories required. Thus, the user principally interested in high-precision work in low-VSWR device design can also make precision calibrations of standard mismatches as well as measurements typical of conventional slotted-line setups.

The outstanding accuracy of the Type 1640-A system carries over to this extended range with no

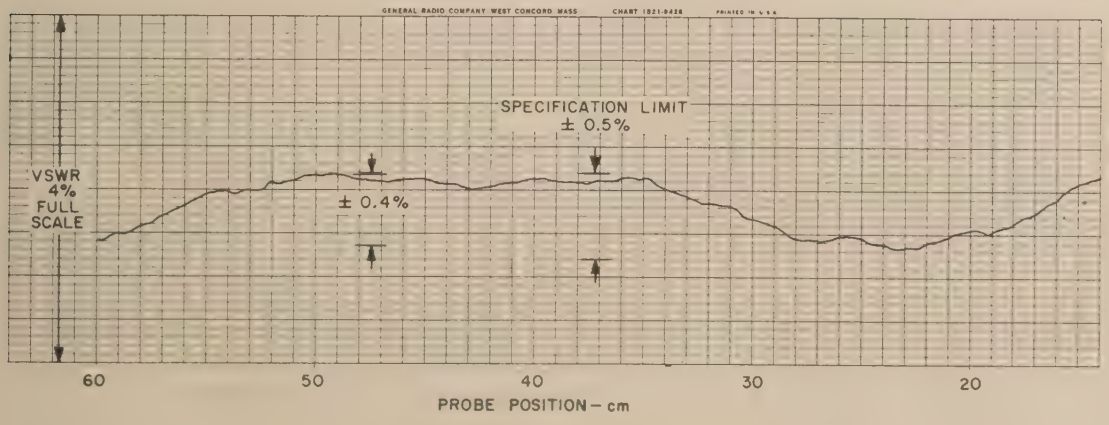


Figure 4-8. Typical flatness performance of Type 900-LB Precision Slotted Line, as plotted on Type 1640-A.

reductions. As a result, standard mismatches and terminations intended for use with precision coaxial elements can be measured with 2% accuracy in reflection-coefficient terms at frequencies between 300 Mc/s and 9.0 Gc/s.

This method is most accurate for values of VSWR between 1.2 and 10. Width-of-minimum techniques, as described in paragraph 3.3.4 of the Type 900-LB Slotted Line instruction book, are recommended if more precise but unrecorded measurements of VSWR > 10 are required.

Since it is impossible to supply a chart paper that is ruled for linear expansions to plot a function approaching infinity, VSWR calibration cannot be used. The related function of reflection coefficient, $|\Gamma|$, however, is quite amenable to linear plots in the range from 0.1 to 1.0, which is roughly comparable to the VSWR range of 1.2 to ∞. Either chart paper supplied can be used for these plots, but the paper with 10 major divisions (Part No. 1521-9310) is much more convenient for many $|\Gamma|$ values.

Recorded measurements of the *phase* of the reflection coefficient can be performed with the same facility afforded in VSWR techniques, so that the observed data can be applied directly to the Smith chart for impedance plots (see paragraph 4.3.6).

4.3.2 MEASUREMENT THEORY.

The rf voltage, E, at any point along the slotted-line probe travel, is equal to the vector sum of the incident and reflected waves, E_i and E_r, at that point, as shown in Figure 4-9. Since the crystal detector operates in the square-law region, its audio output is proportional to the *square* of the rf voltage present in the line. From the geometry of the figure, it can be seen that:

$$E^2 = E_i^2 + E_r^2 - 2E_iE_r\cos\theta$$

where

E = rf voltage on the line
E_i = voltage of the incident wave
E_r = voltage of the reflected wave
θ = phase term, a constant plus $4\pi d/\lambda$
d = distance to the load
λ = wavelength.

The recorder responds to the detected audio output of the crystal detector, V, which is linearly related to the *square* of E as follows:

$$V = k\left|\frac{E}{E_i}\right|^2 = k\,(1 + |\Gamma|^2 - 2\,|\Gamma|\cos\theta)$$

where $|\Gamma| = \left|\frac{E_r}{E_i}\right|$ and k is a constant of proportionality.

Thus, it can be seen that the audio output consists of a steady term, $k\,(1 + |\Gamma|^2)$, and a term that varies sinusoidally with probe position, $-2k\,|\Gamma|\cos\theta$, with a period of $\lambda/2$ and an amplitude proportional to $|\Gamma|$. This effect leads to a convenient method of measuring reflection coefficient with the slotted-line recorder system.

The system is calibrated with a short-circuit termination, ($|\Gamma| = 1$), for which the value of V swings between 0 and 4 k. For any other unknown, V swings between $k\,(1 + |\Gamma|^2 - 2|\Gamma|)$ and $k(1 + |\Gamma|^2 + 2|\Gamma|)$, for a total span of $4k\,|\Gamma|$. The ratio of the swing with the unknown to the swing with a short-circuit termination is just equal to $|\Gamma|$, the reflection coefficient of the unknown.

Note that true square-law detection, a linear indicator for V, and independence of the magnitude of the incident wave from the reflection coefficient of the termination are assumed.

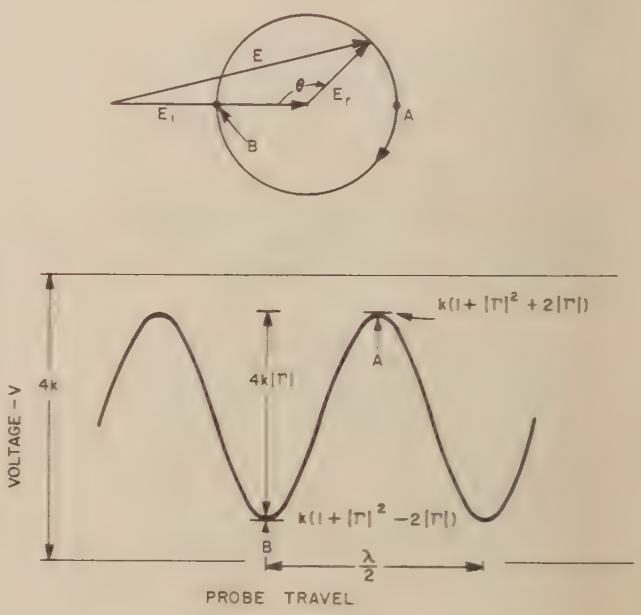


Figure 4-9. Chart calibration in $|\Gamma|$ for large standing-wave pattern in slotted line.

To bring the total span of signals within the recording capability of the recorder, 10 to 20%, V must be superimposed upon a fixed 1-kc signal large compared with V. Then, as V varies from 0 to some small value as a function of probe position, the voltage into the recorder will vary only a small percentage. The pen deflection of the Type 1521-SL Recorder is actually proportional to the *logarithm* of the input signal, owing to the shaping of the VSWR % FULL SCALE potentiometers. But for small percentages the *logarithms* will be linearly proportional to the value of V.

The recorder is, therefore, a suitable linear indicator for this application, provided:

(1) there is an auxiliary audio signal, independent of carriage position, injected in parallel with the signal from the slotted line;

(2) the signal from the line is small compared with the auxiliary signal.

The auxiliary signal is easily generated when an audio oscillator both modulates the rf source and, through a suitable attenuator, injects about 1 mV directly into the recorder input. The second condition is satisfied for settings of the VSWR % FULL SCALE control below 10. For the most accurate measurements of reflection coefficient, the small scale distortion introduced by the above approximations can be corrected with the following formula:

$$\Gamma = \Gamma_m \left[1 - \frac{S}{200}\left(1 - \Gamma_m^2\right)\right]$$

where Γ = actual reflection coefficient of the unknown
Γ_m = measured value of the reflection coefficient
S = setting of the VSWR % FULL SCALE control (%).

The requirement that the magnitude of the incident wave be independent of the reflection coefficient of the load can be satisfied by the matching of the source at the input to the slotted line. The method of measuring source mismatch is covered in the Type 900-LB Slotted Line operating instructions, paragraph 4.8.

An alternate method is to make two measurements and average the results. A Type 900-LZ Reference Air Line must be used that is an odd multiple of a quarter wavelength at the measurement frequency. Two measurements of the short-circuit termination (with and without the air line) and two measurements of the unknown must be made. The incident wave will be slightly high in one case, slightly low in the other, but will average the value that would have obtained with a matched source, as long as the actual source mismatch is less than 1.2:1.

4.3.3 EQUIPMENT REQUIRED.

The standard Type 1640-A system must be modified slightly, as shown in Figure 4-10. Any rf oscillator capable of external modulation with 20–30 volts at 1 kc/s may be used. The 1-kc source required in this setup is used both to modulate the rf oscillator and to provide an input to the recorder. The audio source must have a ±2% frequency-adjustment capability.

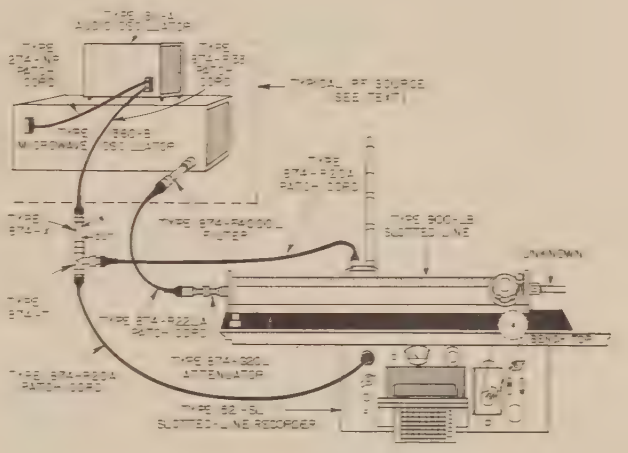


Figure 4-10. Setup for measurement of reflection coefficient with the Type 1640-A Slotted Line Recorder System.

The direct input from the audio oscillator must be attenuated (to ≈ 1 mV) from the value needed to modulate the rf oscillator. Values for the attenuator elements given in the network shown in Figure 4-11 are necessary for the proper operation of the crystal detector within its square-law region, over a wide dynamic range. Procedures to ascertain square-law operation are given in paragraph 4.3.11.

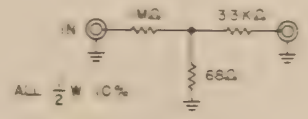


Figure 4-11. Details of attenuator circuit called for in Figure 4-10. It will mount in the Type 874-X Insertion Unit.

Mismatch between the slotted line and the rf source can be a troublesome limitation. In every case, the Type 874-G20L 20-dB Attenuator is recommended both to avoid frequency pulling and to minimize source mismatch. For ultraprecise measurements, the source should be matched with a coaxial tuner, as described in paragraph 4.3.8, so that re-reflections from the mismatch can be excluded from the measurement indication.

4.3.4 CALIBRATION PROCEDURES.

To calibrate the system in terms of reflection coefficient, proceed as follows:

a. Set the recorder INPUT SIGNAL LEVEL control to 1 mV and the VSWR % FULL SCALE control to 10.

b. Adjust the audio oscillator Δf control for a peak indication on the SET LEVEL meter.

c. Disconnect the rf signal input and adjust the recorder ISL control for a pen deflection exactly to the right-hand margin of the chart paper.

d. Attach the Type 900-WN Short-Circuit Termination to the load end of the slotted line and reattach the rf source.

e. Set probe penetration to 0.100. Resonate the probe-tuner assembly on the slotted line, as indicated by maximum pen deflection.

f. Move the probe carriage to a voltage maximum on the standing-wave pattern and adjust the rf source to deflect the pen exactly to the left-hand margin.

g. Move the carriage to a voltage minimum and observe that the pen returns to the right-hand margin.

h. Run a plot of the short circuit, which should be a full-scale sine wave representing a $|\Gamma|$ of 1 (Figure 4-12).

The system is now calibrated in reflection-coefficient terms, and the VSWR % FULL SCALE control can be used to expand the presentation in $|\Gamma|$, provided other controls remain unaltered. Thus, a VSWR % FULL SCALE setting of 5 is equivalent to a $|\Gamma|$ of 0.5 full scale; the chart paper is linear down to $|\Gamma| = 0.1$, with a resolution of one minor division.

NOTE

Expansions down beyond 1% should not be used. Instead, make the measurement of VSWR less than 1.10 in the usual manner.

4.3.5 ROUTINE Γ MEASUREMENTS.

For measurements in which second-order-effect errors are not important, proceed as follows:

a. Remove the Type 900-WN termination and replace it with the unknown.

NOTE

If the unknown is fitted with a connector other than the GR900, select the appropriate adaptor from Table 2-2.

b. Run a plot of the unknown over at least two cycles, as in Figure 4-12, and calculate the reflection coefficient from the total excursion of the sine wave, relative to full scale on the chart paper.

c. For a Smith-chart plot of the measurement, measure d, the distance between minima, and λ, the wavelength, on the strip chart. Calculate d/λ and enter the Smith chart at this value, on the WAVELENGTH TOWARD GENERATOR scale.

To convert the $|\Gamma|$ reading to VSWR, use the right-hand scale of the nomograph of Figure 3-6 in the Type 900-LB instruction book, or use the following formula:

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

For small Γ, reduce the setting of the VSWR % FULL SCALE control to expand the sine wave for better display. Convenient expansions with the Part No. 1521-9428 paper are 8% and 4% full scale. The 10-major-division chart paper (Part No. 1521-9310) is more convenient to use at all other expansions.

4.3.6 SUBSTITUTION MEASUREMENT OF Γ.

The reflection coefficient can be measured more accurately by substitution techniques with this system, with some additional equipment to compensate for possible source-mismatch errors. The Type 900-LZ

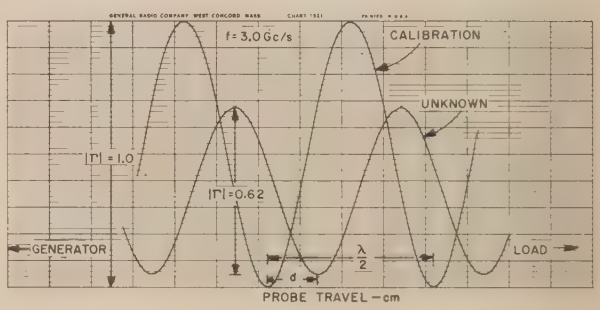


Figure 4-12. Plot of routine reflection coefficient measurement.

Reference Air Lines (paragraph 4.2.3) and the companion short-circuit termination, Type 900-WNC (paragraph 4.3.10), must be used. Measurements must be made at the frequencies appropriate to the air line in use, as listed in Table 4-1.

The procedure is as follows:

a. Calibrate the chart scale as in paragraph 4.3.4, with a Type 900-WNC termination substituted for the Type 900-WN.

b. Run a plot of $|\Gamma| = 1.0$ (Figure 4-13). Lift the pen and manually return the probe to the starting point.

c. Insert the Type 900-LZ Line between the slotted line and the short-circuit termination and run a second plot superimposed upon the first one. (If the plot goes off-scale, reduce the rf input and repeat steps b and c.)

d. Remove the air line and the termination. Lift the pen and return the probe to the starting point.

e. Connect the unknown, and run a third plot. Lift the pen and manually return the probe.

f. Insert the air line between the unknown and the slotted line and run a fourth plot. The chart record is complete and may be removed.

Magnitude of Reflection Coefficient.

Average the results of the four curves of Figure 4-13 to obtain a value of $|\Gamma|$, referred to the characteristic impedance of the Type 900-LZ Reference Air Line and corrected for source-mismatch errors.

a. Sum the two sine-wave amplitudes obtained for the short-circuit termination; a+ b.

b. Sum the two sine waves obtained for the unknown; f + g.

c. Divide the result of step b by that of step a, to obtain the measured value of Γ_m; $\Gamma_m = \frac{f + g}{a + b}$.

d. Correct for scale distortion, to obtain the actual value of Γ:

$$\Gamma = \Gamma_m \left[1 - \frac{S}{200} (1 - \Gamma_m^2)\right]$$

Phase of Reflection Coefficient;

The phase may be measured as before. The value of d is the distance between a minimum of the unknown and an adjacent minimum of the short-circuit termination, both taken without the air line. A slightly more accurate value of d is obtained from the crossover points of the UNKNOWN plots relative to crossover points of the CALIBRATION plots, as indicated in Figure 4-13.

The interval spanning three adjacent zero crossings of the CALIBRATION curve is $\lambda/2$ at the test frequency. Compute d/λ to get the value for entry into the WAVELENGTH TOWARD GENERATOR scale of the Smith chart.

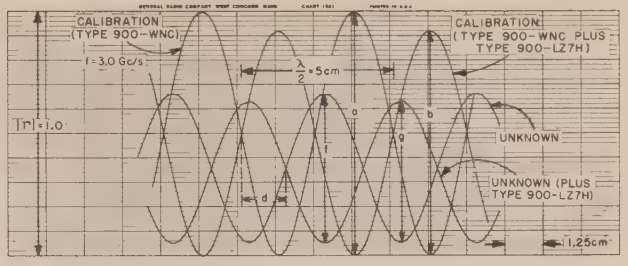


Figure 4-13. Substitution measurement of reflection coefficient. Inequality of $|a|$ and $|b|$ attributable to source mismatch.

EXAMPLE: In Figure 4-13, the measurement was performed with a Type 900-W200 200-Ohm Termination as the UNKNOWN. The theoretical VSWR of such a termination is 200/50 or 4:1; the corresponding reflection coefficient $|\Gamma| = \frac{4 - 1}{4 + 1} = 0.600$. Following the above procedure, the measured magnitude of the reflection coefficient is given by:

$$\Gamma_m = \frac{f + g}{a + b} = \frac{0.61 + 0.58}{0.995 + 0.92} = 0.621.$$

The VSWR % FULL SCALE control was set for 10, so the corrected value for Γ is:

$$\Gamma = 0.621 \left[1 - \frac{10}{200} (1 - 0.621^2)\right] = 0.604.$$

The VSWR of the termination is

$$\text{VSWR} = \frac{1 + 0.604}{1 - 0.604} = \frac{1.604}{0.396} = 4.05$$

which is very close to the theoretical value of 4.00 for an ideal 200-ohm termination.

The phase of the reflection coefficient is determined from values of d and λ. In the original chart record (before reduction), d measured 0.72 inch and λ measured 2.47 inches. The value of d/λ is, therefore, 0.72/2.47 = 0.292. This value on the WAVELENGTHS TOWARD GENERATOR scale of a Smith

chart yields the phase of the reflection coefficient, -30°.

The result of the measurement in terms of reflection coefficient is:

$$\Gamma = 0.604 \angle -30°$$

and in terms of VSWR:

$$VSWR = 4.05, \frac{d}{\lambda} = 0.292$$

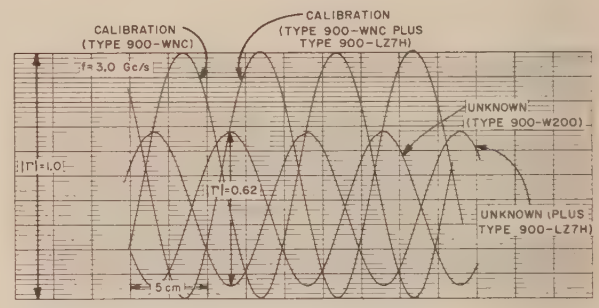


Figure 4-14. Substitution Γ measurement made with a matched source. Contrast the uniform sine-wave plots with those of Figure 4-13.

4.3.7 PRECISION Γ MEASUREMENT.

Reflection coefficient measurements can be made well within 2% accuracy limits, if the techniques of paragraph 4.3.6 are preceded by careful elimination of source mismatch, and if the Γ readings are corrected for scale-distortion error. A source mismatch of 1.1, uncorrected, can cause 21% error in the measured Γ, and scale-distortion error another 5% (both in the worst case).

Source mismatch can be measured according to the procedures given in paragraph 4.8 of the slotted-line instruction book. The mismatch should be reduced as low as possible for ultraprecise measurements.

As shown in Figure 4-13, the source mismatch can cause large errors in slotted-line measurements. The larger the load mismatch, the greater the magnitude of the source re-reflection. Thus, it is particularly a problem in these reflection-coefficient measurements with the slotted-line recorder.

In this application, the system displays the square of the source VSWR. Since it is not uncommon to have a source that presents a 2:1 mismatch, the necessity of being able to counteract this effect becomes quite apparent.

A major first step is to isolate the source through a 20-dB pad, such as the Type 874-G20L. Substitution measurements performed with the Reference Air Lines can compensate mismatch effects within the range of 1.2:1, as shown in Figure 4-13.

The recommended procedure is to tune out the source mismatch by the method described in paragraph 4.3.8 and then to utilize the air-line substitution method. This eliminates both source mismatch and slotted-line errors. Results typical of what can be expected under these circumstances are shown in Figure 4-14.

4.3.8 SOURCE-MATCHING PROCEDURE.

Source mismatch, which is of greater consequence with oscillators than it is with signal generators, can be excluded from the reflection-coefficient measurements of relatively large-mismatch unknowns. The equipment setup shown in Figure 4-15 permits a match of any source, throughout the frequency range of the Type 1640-A.

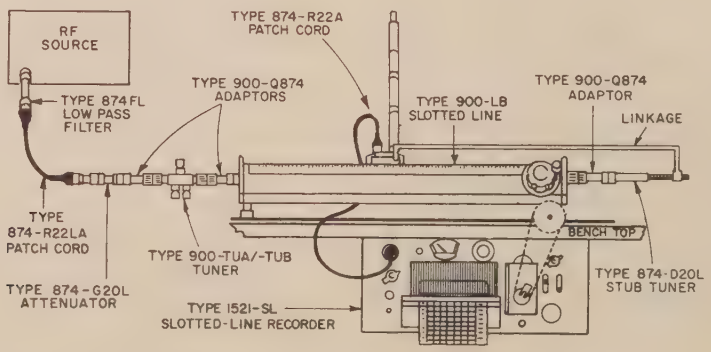


Figure 4-15. Equipment required to match a source to the Type 1640-A System.

The setup calls for the addition of the GR900 tuner needed to achieve the match at the input end of the slotted line and a sliding short circuit (plus a means of linking it to the probe carriage) at the unknown end.

The Type 900-TUB should be used as the tuner, at frequencies from 0.25 - 2.5 Gc/s, and the Type 900-TUA at frequencies from 1.0 to 9.0 Gc/s. The Type 900-Q874 Adaptor will be required at each port of the tuner.

The Type 874-D20L Adjustable Stub, fitted with a Type 900-Q874 Adaptor, should be used as the sliding short circuit. A simple linkage should be contrived to connect the end of the stub with the probe carriage on the slotted line. It should be long enough to extend from the end of the stub (in fully retracted position) to the near screw in the carriage vernier plate. The probe should be positioned to allow for at least 20 cm of travel to the load end of the line.

The procedure is as follows:

a. Set up the system in the usual manner, with the tuner (all screws set to 5.0) and the stub attached.

b. Set the probe at a voltage maximum, as indicated by maximum pen deflection to the left, and lock the linkage.

c. Plot the VSWR of the source on an appropriate scale expansion near the bottom on the strip chart.

d. Adjust the tuner and repeat the plot, using the convergence-to-match procedure given in paragraph 4.2.7, until the mismatch effect is eliminated.

e. Remove the stub, its adaptor, and linkage, and measure the reflection coefficient of unknowns, as in paragraph 4.3.5.

4.3.9 MEASUREMENT OF STANDARD MISMATCHES.

After the source has been matched (paragraph 4.3.8), the reflection coefficient can be measured directly, without resort to substitution measurements. For example, in Figure 4-16, several GR900 standard mismatches are compared with the Type 900-WN Short-Circuit Termination. Table 4-2 summarizes the results of the measurements.

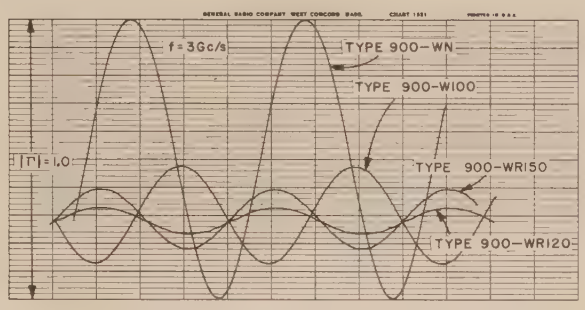


Figure 4-16. Measurements of various GR900 Mismatch Terminations with a matched source impedance.

4.3.10 TYPE 900-WNC TERMINATION.

In applications with the slotted line recorder system that call for attachment of a short-circuit termination to a Type 900-LZ Reference Air Line, the Type 900-WN termination (supplied) cannot be used. Since it is a flush disk-type termination, it cannot provide the center-conductor support that the beadless line requires.

The Type 900-WNC termination is a very low-loss short circuit, designed specifically for the Type 900-LZ Reference Air Lines but suitable as well for any transmission line fitted with the GR900 connector. The reference plane of the short circuit occurs exactly at the reference plane of the GR900 connector. The reflection coefficient is 0.999, or greater, to 9.0 Gc/s.

The device comprises a precision-machined, silver-plated, brass slug, gold-plated for tarnish protection, with necessary GR900 coupling hardware.

TABLE 4-2

MISMATCH MEASUREMENTS

Termination Type	*Theoretical VSWR*	*Theoretical* $\|\Gamma\|$	*Measured* $\|\Gamma\|$	*Correction Factor*	*Actual* $\|\Gamma\|$	*Actual VSWR*
900-WN	∞	1.000	1.000	1.0	1.000	∞
900-W200*	4:1	0.600	0.622	0.968	0.602	4.03:1
900-W100	2:1	0.333	0.355	0.955	0.338	2.02:1
900-WR150	1.5:1	0.200	0.210	0.95	0.200	1.50:1
900-WR120	1.2:1	0.091	0.090	0.95	0.086	1.19:1

* from Figure 4-14.

Also included is a GR900 center contact, which engages the pin insert of the reference air line to support its center conductor.

The short-circuit disk makes a butt contact with the outer conductor of the mating line or connector. The spring-loaded center contact (which protrudes slightly) is compressed to make the center-conductor junction in the same plane.

4.3.11 VERIFICATION OF SQUARE-LAW OPERATION.

Square-law operation of the slotted-line crystal detector is easily verified after the source-matching procedure has been carried out.

Plot successively the reflection coefficient curves for Type 900-WNE, Type 900-WO, and Type 900-W50 Terminations, as shown in Figure 4-17. Proper square-law operation is ensured if the crossover points of the Types 900-WNE and -WO Terminations fall at midscale (after correction) of the chart paper, and if the Type 900-W50 Termination falls at the one-quarter-full-scale point, after correction.

For example, in Figure 4-17 the scale expansion employed is 10% full scale. The crossover of the Type 900-WNE and Type 900-WO curves is at 0.52, and the Type 900-W50 curve is a straight line at 0.26. Corrected values are

$$0.52\left[1-\frac{10}{200}\left(1-0.52^2\right)\right]=0.50$$

and

$$0.26\left[1-\frac{10}{200}\left(1-0.26^2\right)\right]=0.25$$

These occur at the proper values, so the detector is operating in its true square-law mode.

If the above results cannot be duplicated, try a different crystal in the slotted line.

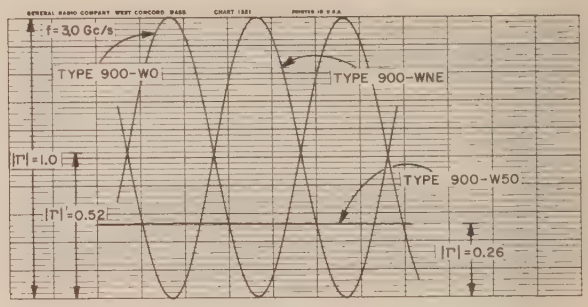


Figure 4-17. Comparison plots made with various terminations to verify system square-law operation.

4.3.12 AMPLITUDE STABILITY OF SIGNAL SOURCES.

The Type 1640-A system can be used to record the short-term stability of the amplitude of the output of an rf signal source, within an accuracy of 0.002 dB.

In such an application, the slotted-line portion of the system is used only as a convenient tuned detector and the probe carriage is not moved for the measurement. The CHART DRIVE can be set to any convenient paper speed for this application.

Figure 4-18 is the chart record showing the short-term amplitude stability of a high-quality microwave oscillator in the presence of line-voltage fluctuations. The scale expansion is 1% full scale (0.08 dB). The line voltage into the oscillator was varied from 110 to 120 volts, at a rate of 1 cycle per second, by means of a Variac® adjustable autotransformer driven by a Type 1750-A Sweep Drive.

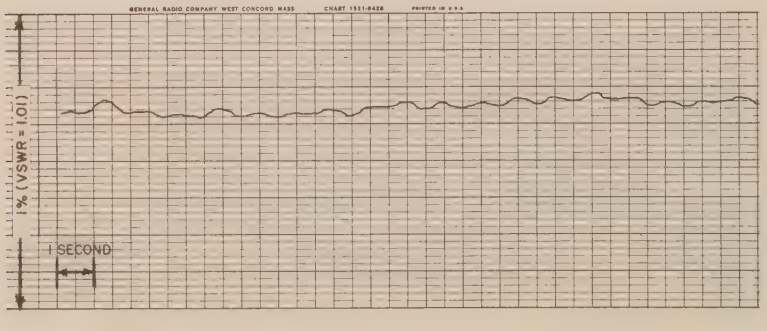


Figure 4-18. Source amplitude stability in presence of 10-volt peak-to-peak line-voltage excursions at 1-cycle rate, as measured in a Type 1640-A Slotted Line Recorder System.

SECTION 5

PRINCIPLES OF OPERATION

5.1 INTRODUCTION.

The Type 1640-A Slotted Line Recorder System automatically produces precision-calibrated recordings of small standing-wave patterns and other slotted-line measurement phenomena. With such a system, VSWR's from 1.001 to 1.200 can be rapidly measured and accurately recorded.

The system consists of the Type 900-LB Precision Coaxial Slotted Line equipped for automatic-recorder operation by connection to the Type 1521-SL Slotted Line Recorder via a mechanical-linkage unit, through which the recorder drives the carriage of the slotted line.

The output of the system produces a continuous and permanent measurement record which can be analyzed graphically for the most accurate determination of the magnitude *and* phase of a standing-wave pattern. Positions of minima, with a short circuit at the reference plane, can also be plotted automatically.

The system is operated with a 1-kc square-wave-modulated rf input signal, and the resulting output from the slotted-line diode detector actuates the recorder for an adjustable expanded-scale VSWR presentation. Audio levels, continuously variable from 0.05 to 2 millivolts, can be accommodated by the recorder to permit on-scale operation at the level producing the best signal-to-noise ratio. The VSWR-equivalent noise level of the recorder is 1.0001.

The presentation appears on a strip chart with a 4-inch recording width. The chart's vertical scale has eight or ten major divisions, each of which has five minor divisions. The horizontal chart scale, ruled in ¼-inch intervals, can be calibrated in either 0.5- or 1.0-cm units, by selection of an appropriate drive sprocket. This scale relates directly to the centimetric probe-travel scale of the slotted line, which in turn is calibrated with respect to the reference plane located at the contact surfaces of the GR900 connector at the load end. Probe position can be plotted to 0.1-cm accuracy and can be manually reset for substitution measurements.

System accuracy derives from the 0.1-1.0% accuracy of the Type 900-LB Precision Slotted Line, the 0.05% repeatability of the GR900 precision coaxial connector on the slotted line, and the wide servo bandwidth and fast writing speed of the recorder. The VSWR accuracy of the strip-chart recording depends only upon three stable, wire-wound potentiometers in the recorder servo loop, which are custom calibrated in each instrument.

Material in this section will be limited to an explanation of the principles of operation of the Type 1521-SL recorder and the techniques whereby it con-

verts the audio output of a slotted-line detector to a highly expanded strip-chart recording of the standing-wave pattern in the line.

NOTE

A comprehensive treatment of the theory of slotted-line measurements, along with descriptive information on the Type 900-LB, is covered in detail in a separate manual supplied with that instrument.

5.2 TYPE 1521-SL RECORDER (Figure 5-1).

5.2.1 GENERAL.

The Type 1521-SL Slotted Line Recorder is a transistorized, single-channel, suppressed-zero, servo-type instrument. It produces an ink record on white chart paper, translucent for reproduction. Edge perforations on the paper mesh with drum-mounted sprockets, to advance the strip. The reversible paper feed offers both manual and automatic options, with four switch-selectable motor speeds available in the automatic mode. Adjustable rotary switches can be preset to limit motor drive and probe travel in either direction.

In operation, a capillary pen is moved across the chart paper by a null-seeking servo which travels linearly. The difference between the slotted-line detector-output voltage and an internally generated reference voltage is amplified and used as the error signal to position the pen. A contact attached to the servo motor rides along a straight-line potentiometer, which is the balancing element, while a velocity-feedback coil, also mounted on the servo-motor coil assembly, furnishes appropriate damping.

Front-panel controls permit continuous, calibrated, full-scale adjustment over the VSWR range, and are augmented by a gain control (and associated drive-level monitor) to keep response within the range of the slotted-line diode detector.

The Type 1521-SL records the level of 1-kc signals over an adjustable scale expansion of 0.13 to 3.17 dB full scale (see Figure 5-2). These expansions correspond to VSWR's of 1.008 and 1.20, full scale, when the recorder is used with the Type 900-LB slotted line, which has a square-law crystal detector. A high-speed servo-motor simultaneously positions the recorder pen and the wiper arm of a servo-error balancing potentiometer, through a straight-line drive mechanism, to produce an ink trace on rectilinear chart paper. The servo loop adjusts the potentiometer to keep the signal output of the input-attenuator network constant. Thus, changes in the input signal show up as corresponding changes in the positions of the wiper arm of the potentiometer and of the pen.

The taper of the servo-error balancing-unit potentiometer compensates for the square-law function

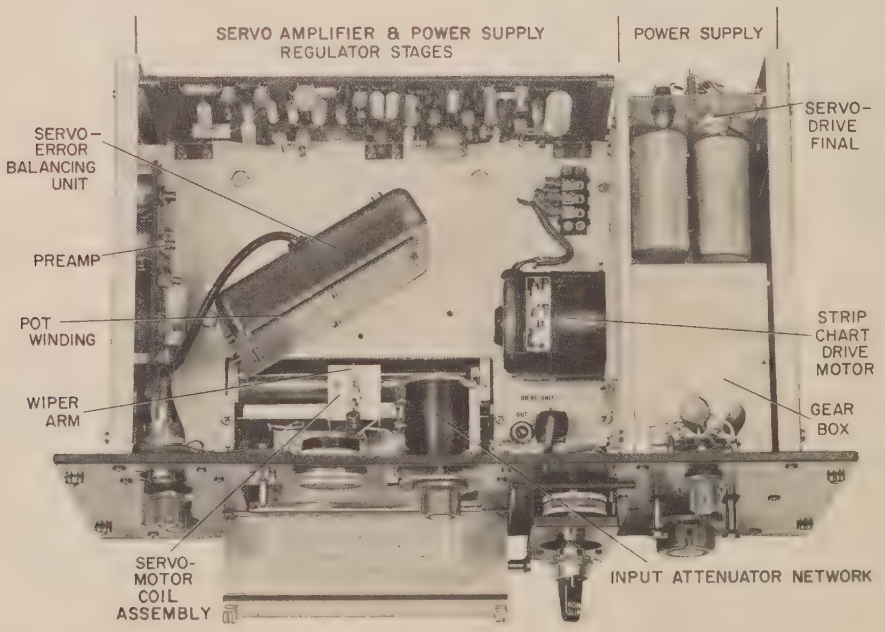


Figure 5-1. Major elements of the Type 1521-SL Recorder (top interior view).

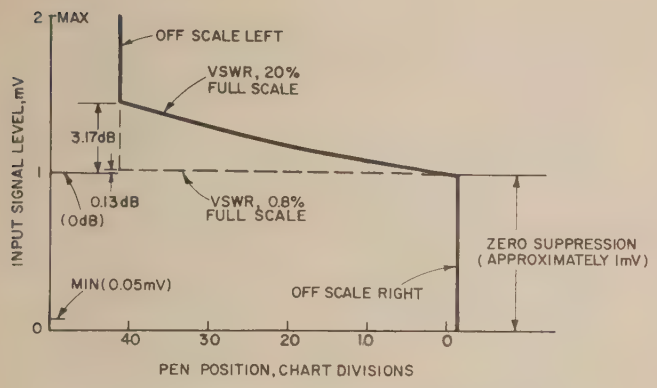


Figure 5-2. Recorder pen position as a function of input signal level from the slotted line detector.

of the input signal and linearizes the VSWR scale of the chart recording. Variable scale expansion and linearity of chart scales in VSWR are obtained simply by the use of ganged variable resistors in the attenuator network.

The strip chart is driven by a synchronous motor through a four-speed gear box, which also drives an external sprocket. Through a mechanical linkage unit, this sprocket drives the carriage of the slotted line in synchronism with the strip chart. The recorder output therefore displays the voltage on the slotted line as a function of the probe position and is a permanent picture of the standing-wave pattern on the line.

5.2.2 OVERALL OPERATION.

The block diagram in Figure 5-3 illustrates in more detail the operation of the recorder. The signal is preamplified before it reaches the servo-controlled input attenuator, in order to obtain and preserve the best possible signal-to-noise ratio. Low-noise transistors are used and the circuit parameters are adjusted to minimize the noise figure at a source impedance of about 30 kilohms, the impedance of the average crystal detector. The 25-dB gain of the preamplifier allows first-stage noise to override the noise of all succeeding stages.

A high-input-impedance amplifier follows the input attenuator, to prevent distortion of the law of the balancing potentiometer, as a result of loading.

The 1-kc tuned amplifier provides selectivity and is actually tuned slightly below 1 kc/s to prevent possible beating of the input signal with the harmonics of 60 c/s that fall at 960 and 1020 c/s.

The servo detector is a full-wave bridge rectifier (for cancellation of the fundamental) that feeds dc to one side of the differential amplifier that follows. The other input to the differential amplifier is a 1-Vdc reference derived from a Zener-diode-regulated supply.

The dc output of the differential amplifier is the error signal for the pen-positioning servo-mechanism, which drives the pen to the left if the rectified input signal is larger than the reference voltage, and vice versa, until the error signal is essentially zero.

The unusual straight-line servo motor consists of a multi turn drive coil supported in the field of a permanent magnet. Fields set up by direct current passing through the coil interact with the magnetic field and force the coil to the left or right, depending on the sign of the current. Equilibrium is reached when the error signal is zero, which reduces the current through the coil to zero also.

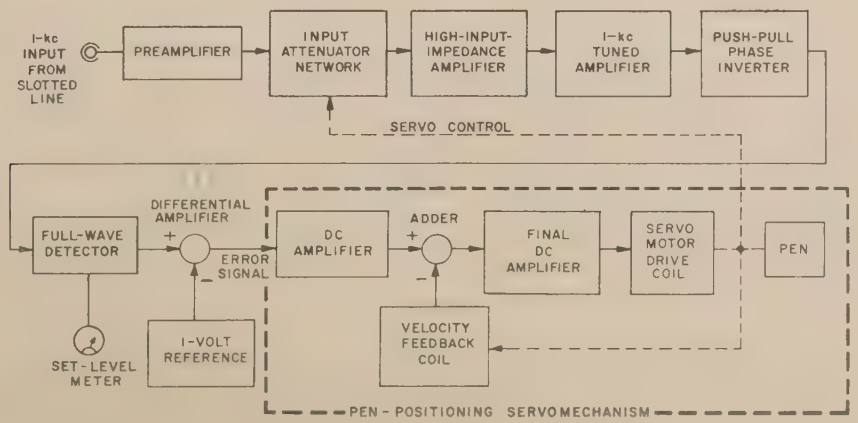


Figure 5-3. Block diagram of the Type 1521-SL Slotted Line Recorder.

A velocity feedback coil, mounted coaxially with the drive coil, supplies a dc signal proportional to the velocity of drive-coil motion. The polarity of the signal depends on the direction of motion of the drive coil. A portion of this signal is added to the error signal ahead in the final dc amplifier to prevent oscillation of the servo loop, and to vary the bandwidth of the servo amplifier. The amount of damping required to prevent oscillation depends upon the setting of the VSWR % FULL SCALE control, because this latter control affects the servo-loop gain. That is, the higher the full-scale setting of the control the less the required setting of the DAMPING control.

5.3 DETAILED CIRCUIT DISCUSSION.

NOTE

The full schematic diagram, plus interior views of the instrument given in Section 6, should be consulted for a more complete understanding of the discussion in the following paragraphs.

5.3.1 PREAMPLIFIER.

The preamplifier has a noise figure of less than 5 dB at an optimum source impedance of 30 kilohms. The input transistor is protected from accidental damage due to large overloads by a limiter consisting of a series capacitor, C400, and two shunt silicon-rectifier diodes CR400, CR401. Normally the amplifier need not handle more than a 2-mV input signal, the upper limit of square-law operation of the crystal detector of the slotted line.

The first stage, Q400, is a common-emitter amplifier for maximum gain and the second and third stages (Q401, Q402) are common-collector amplifiers to reduce the output impedance of the first stage to the low impedance required to drive the attenuator network.

The preamplifier has two outputs. selected by a front-panel control (S401), which differ in gain by about 25 dB. The lower of the two, VSWR, is for standing-wave-pattern recording; the high-gain output, REF PLANE, is for recording the position of minima on the line with a short circuit at the reference plane. The extra gain is needed to reduce the recorded width of the minima, for best accuracy in the determination of their positions.

For precision VSWR measurements, the large scale expansion offered by the recorder is absolutely necessary. However, for position-of-minimum measurements with short- or open-circuit terminations, the widths of the minima of the VSWR mode are too great for precise resolution of the position of the reference plane. Thus, in the REF PLANE mode the recorder has effectively a 20:1 magnification which permits better resolution much deeper in the trough of the minimum as shown in Figure 5-4.

A secondary adjustment, R403, a 10-kilohm potentiometer, is used to set the over-all gain of the recorder in the VSWR mode. It follows the output stage of the preamplifier and is bypassed by S401 in the REF PLANE position.

5.3.2 INPUT ATTENUATOR NETWORK.

The attenuator network, shown in Figure 5-5, through the action of the servo loop, holds the voltage at the input to the high-impedance-amplifier constant while the pen is on-scale and recording a signal. The equilibrium voltage ratio of the attenuator is, therefore,

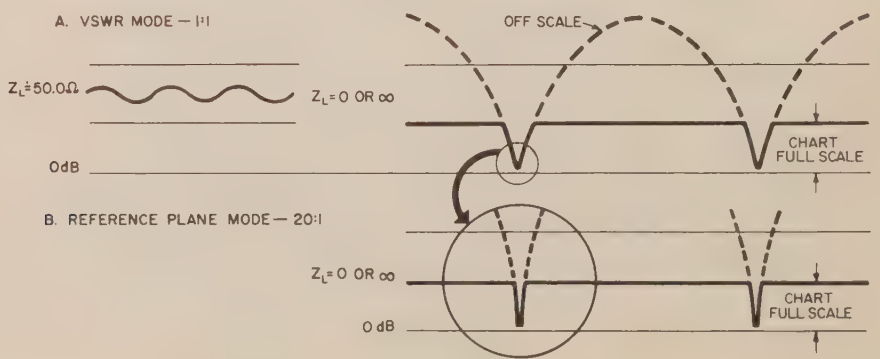


Figure 5-4. Scale expansions available in VSWR and REF PLANE modes of operation.

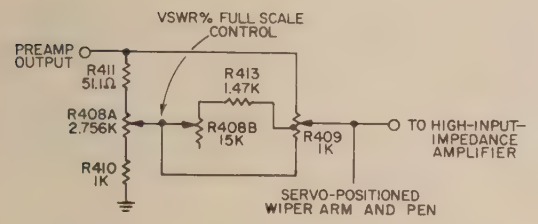


Figure 5-5. Input attenuator network.

inversely proportional to the signal strength. By suitable shaping of potentiometers R408A and B, the scale can be made to fit practically any desired curve of the suppressed-zero type.

Large amounts of scale expansion, so desirable in VSWR measurements, are achieved with an attenuator consisting of a low-valued potentiometer in series with a resistor to ground, R408A and R410. The servo-driven wiper arm of R409, the balancing-unit potentiometer, must then travel the whole length of its winding in response to relatively small changes in the input signal.

The amount of scale expansion is adjusted for different values of VSWR full scale, by manual adjustment of R408A.

The balancing potentiometer winding is center-tapped and shunted with another adjustable resistor R408B, that modifies the potentiometer law slightly, at high values of VSWR, to keep the scale linear in VSWR.

5.3.3 HIGH-INPUT-IMPEDANCE AMPLIFIER.

The high-input-impedance amplifier follows the attenuator network and has an input impedance of over 1 megohm, in order not to load and thereby distort the law of the attenuator. The amplifier consists of two common-emitter stages, Q101, Q102, with negative voltage feedback from the collector of the second stage to the emitter of the first to raise the input impedance.

The low-noise first stage preserves the more than 80-dB signal-to-noise ratio of the input signal. The gain control (R111), marked INPUT SIGNAL LEVEL, follow this amplifier for the same reason.

The range of input-signal levels that must be accommodated is severely restricted by the nature of the signal source. The slotted-line detector must be operated in its square-law region, and the upper limit of square-law operation occurs at about 2 mV. The noise level of the detector, roughly the same as the noise of a resistor, determines the lower limit of operation. The signal-to-noise ratio is, of course, best at 2 mV and degrades linearly with decreasing signal level. The lower limit is set at 0.05 mV, where the crystal noise seriously hampers the recording of low VSWR.

A fine gain control (R112), marked CENTERING, with a range of adjustment of less than 10%, allows the pen to be set easily to any part of the chart paper, even on maximum scale expansion of 0.8%, full scale.

5.3.4 1-KC TUNED AMPLIFIER.

This amplifier consists of a common-emitter stage and a common-collector stage, with negative feedback through a twin-T network from the emitter of the second stage to the base of the first stage. Since there is negative feedback at all frequencies but 1-kc, the over-all response peaks at this frequency and is roughly equivalent to that of a tuned circuit with a Q of about 30 (3.5% bandwidth).

Because of the limited amount of gain required from this amplifier, the output is taken from a small resistor (R120) in the collector of the output stage. Two capacitors, C112 in series and C113 in shunt with the output, further reject frequencies well beyond the passband.

5.3.5 PUSH-PULL PHASE INVERTER.

The signal is next converted from single-ended to push-pull, in order to drive the full-wave detector that follows. The first stage, Q105, is common-collector, and the second, Q106, common base. The emitter current of the first stage almost all flows into the emitter of the second stage, because of the low input impedance of the second stage compared with the impedance of the fixed resistors.

The collector currents of the two stages will, therefore, be of almost the same magnitude but of opposite phase. The output is taken from two resistors in the collectors of the two stages, and one of the collector resistors (R130) is adjustable over a small range to equalize the two outputs exactly.

At balance, the resulting output of the full-wave detector contains no 1-kc component; consequently, a potentially deleterious feedback loop is broken. Any 1-kc signal that gets through the dc amplifier and onto the drive coil feeds back, through the wiper arm of the potentiometer, into the high-impedance amplifier.

5.3.6 DETECTOR.

The detector is a conventional full-wave bridge rectifier, CR101-CR104. One side of the output feeds the differential amplifier, and the other feeds the tuning meter, M401, through a high resistance (R135).

The sensitivity of the tuning meter is adjustable by means of R407 so that deflection of the pen within the confines of the black wedge on the face of the meter can be made to correspond to pen deflection on the chart paper.

5.3.7 DIFFERENTIAL AMPLIFIER.

The differential amplifier consists of two identical common-emitter stages, Q108-Q109, with large amounts of negative feedback. The initial bias at the two base inputs differs by the 1-Vdc drop across resistor R240, in the voltage divider from the 18-Vdc supply to ground. The rectified output of the detector opposes this initial bias and at 1-Vdc there is no difference between the dc outputs of the two stages. The net input to the push-pull dc servo amplifier is, therefore, zero and the recorder pen is at equilibrium. The 1-kc input required to give this 1-Vdc signal depends on the settings of the VSWR % FULL SCALE, INPUT SIGNAL LEVEL, and CENTERING controls in the preceding amplifier chain.

5.3.8 DC AMPLIFIERS.

The output of the differential amplifier is amplified in three push-pull stages, Q110/Q111, Q112/Q113, Q1/Q2, and fed to the drive coil of the pen-positioning servo motor. A small amount of 60 c/s current is fed into the input of the dc amplifier to eliminate the static error of the servo motor. With this signal present, the pen is responsive to the smallest change in the dc input to the amplifier.

The damping signal is also fed into the dc amplifier at this point. Produced by the feedback coil, which is attached coaxially adjacent to the drive coil, this dc signal is proportional to pen velocity. This signal, generated by motion of the coil through the magnetic field, is fed back in opposition to the input signal and, therefore, acts to reduce the velocity of the pen.

This is an effective method for reduction of the servo bandwidth, to eliminate potential instability and to control the noise bandwidth, when slowly varying functions are plotted. Thus, smoother traces are achieved. The proportion of the feedback signal used is adjusted with the DAMPING control (R22) to get servo bandwidths from 1.5 to 6 c/s.

5.3.9 SERVO MOTOR (See Figure 5-6).

The servo motor consists of a center-tapped drive coil wound on a lightweight cylindrical form, positioned in the uniform magnetic field existing in the air gap of a permanent-magnet structure.

The coil assembly is a low-mass, hollow cylinder which surrounds a precision-machined rod-shaped portion of the magnet structure. Two polished steel guide rods, parallel with the magnet rod, provide low-friction support for the assembly, with a few thousandths clearance from the rod.

A precision machined shoe is an opposing pole piece to the iron rod in the magnet structure. The pieces are aligned to furnish a uniform air gap through which the coil winding travels.

Rubber stops at the ends of the top guide rod prevent damage to the coil assembly, if it slams against a limit.

The interaction of the electric field in the coil and the field from the permanent magnet is used to move the coil in a direction to reduce the error voltage.

When the drive coil is correctly positioned, the wiper arm is moved to a position on the potentiometer winding of the servo-error balancing unit to reduce the input signal sufficiently to preclude further generation of an error signal from the differential amplifier. The absence of an error signal cuts off the amplifier, with the result that current in the drive coil goes to zero and the coil is momentarily in equilibrium. Thereafter, any slight departure from the correct null position will produce an electrical restoring force on the coil.

The pen and the potentiometer wiper arm are mounted directly on the coil assembly, so that backlash is negligible.

5.3.10 POWER SUPPLY.

The power supply is energized from a 16-volt winding on the transformer T1 which feeds two half-wave rectifiers, CR1/CR2, to give 45 Vdc, unregulated. This is reduced to 26 Vdc, regulated, with a series-regulator circuit consisting of two Zener diodes (CR110, CR111), a pilot light (P201), and a series dropping transistor (Q3). This supply feeds the less critical dc amplifier stages.

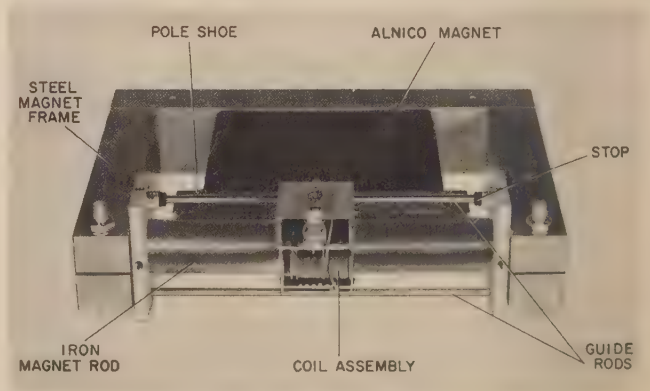


Figure 5-6. Details of recorder servo-motor.

The 26 Vdc is further reduced to 18 Vdc, through an adjustable, regulated supply, for the most critical stages. Two control transistors (Q114 and Q115) are used with an error-sensing feedback transistor (Q116) and a Zener diode (CR107) in the regulator. A potentiometer adjustment with a small range, R168, allows the output to be set to exactly 18 Vdc.

5.3.11 PAPER SPEED.

The paper is driven by a synchronous motor, MO1, at speeds of 2.5, 7.5, 25, or 75 in/min. These speeds correspond to 10, 30, 100, and 300 cm/min travel of the probe along the slotted line, with the small sprocket; 5, 15, 50, and 150 cm/min with the large sprocket. Speed changes are easily made while the motor is running by means of two front panel gear-shift levers; a neutral position is also available.

The chart paper can be motor driven, either forward or backward, or controlled manually. In normal operation the chart is driven in the forward direction at a chart speed commensurate with the frequency of operation and the sprocket in use, as shown in Table 3-2. The chart may be returned to the starting position, either manually with the slotted-line control knob, or automatically by reversal of motor direction.

Chart paper and slotted-line carriage can be driven independently, if the front-panel DRIVE UNIT is de-clutched, with the lever placed in the IDLE position.

SECTION 6

SERVICE AND MAINTENANCE

NOTE

Material in this section pertains to the recorder portion of the system only. Refer to the separate manual supplied for slotted-line service information.

6.1 WARRANTY.

General Radio Company warrants that each new instrument sold direct is free from defects in material and workmanship, and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel, will be repaired, or, at our option, replaced without charge, except for tubes, semiconductors, or batteries that have given normal service.

6.2 FACTORY SERVICE.

The two-year warranty stated above attests the quality of materials and workmanship in General Radio products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the type and serial numbers of the instruments.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office, requesting a "Returned Material Tag." Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

6.3 CLEANING AND LUBRICATION.

6.3.1 MOTOR.

The lubrication port on the top of the paper-drive motor (MO1) is sealed by a small screw. Temporarily remove this screw and apply 20 drops of oil every three months. Recommended lubricants are Stanoil No. 35 (Standard Oil Co. of Indiana) and Gulfcrest C (Gulf Oil Co.).

6.3.2 GEAR BOX.

The gear box should *not* be lubricated, or it will collect dirt and cause noisy operation. Self-lubricating bearings are used with moving parts throughout the recorder.

6.3.3 GUIDE ROD.

The guide rod on which the servo-motor coil assembly rides should be cleaned with a soft dry cloth to ensure maximum writing-speed capability.

CAUTION

Under no condition should the guide rod be oiled.

6.3.4 SERVO-MOTOR POTENTIOMETER.

For best performance, clean and lubricate the servo-motor potentiometer monthly with the NO-OX solution supplied. This unit, R409, should be removed from the recorder for cleaning. Removal can be accomplished from the front, through the chart well. The procedure is as follows:

a. Unplug PL2 from the top of the unit and push the cord to the left, for clearance.

b. Release the knurled captive screws at either end of the potentiometer.

c. Carefully lift the unit straight up, about one-half inch, to disengage the guide pins and to clear the wiper arm and pen.

d. Withdraw the unit from the recorder, holding it level and as close to the top of the chart-well opening as possible.

e. Apply a small amount of NO-OX on the winding, which protrudes through the bottom, then wipe it off with a clean, lint-free cloth.

f. Apply a second coat for lubrication.

g. Reverse the removal procedure to reinstall the potentiometer.

NOTE

The potentiometer winding must be at the front end.

h. Lower the unit gently in place, so that the guide pins engage and the winding rests lightly on the wiper arm.

6.3.5 PEN.

To clean the pen, pull it straight out from its spring-clip mount and shake the ink from the reservoir. Rinse the pen with water and run the point along a piece of chart paper to remove the remaining ink from the capillary tube. If the tube is clogged, free it with one of the thin wires supplied. Refill with fresh ink (no more than 4/5 th full).

6.4 SERVICE INSTRUCTIONS.

The information in the following paragraphs should be sufficient to permit proper maintenance of the recorder so as to ensure continued performance within specification. Included are minimum-performance standards, trouble-analysis, and repair and adjustment procedures. The text material is presented largely in tabular form for easy reference and is comprehensively supplemented by illustrations. Reference designators for detail parts cited in text and illustrations correspond to those used on the over-all equipment schematic, Figure 6-10, and in the parts list at the end of this section. The following procedures presuppose a working familiarity with the principles of operation of the recorder, as presented in Section 5.

6.5 MINIMUM PERFORMANCE STANDARDS.

6.5.1 GENERAL.

Procedures needed to validate *recorder* accuracy appear in the following paragraphs. They should be used whenever system-calibration procedures (Section 4) fail to check out, or if system operation appears marginal. These procedures should also be used if any repairs or internal adjustments have been made. A list of recommended test equipment for bench testing of the recorder appears in Table 6-1; equipment of equivalent capabilities can be substituted. Arrange the test setup as shown in Figure 6-1.

NOTE

Where possible, neither terminal of any test equipment should be connected to case ground, to avoid ground loops.

In the event that, in any of the procedures in paragraphs 6.5.2 through 6.5.6, the recorder fails to achieve satisfactory performance, refer to the trouble-analysis procedures (paragraph 6.6) to isolate the defect for corrective action.

6.5.2 PRELIMINARY ADJUSTMENTS.

1. Oscillator:
   FREQUENCY - 1 kc/s, tunable ±2%.
   MAXIMUM OUTPUT - 3 volts, open circuit.
   OUTPUT connector - Ungrounded
   △F control - Adjust for 990 c/s as indicated on counter.
   OUTPUT control - Adjust for 1 volt as indicated on voltmeter.
2. Ratio Transformer:
   X.001000
3. Recorder (Figure 6-2):
   REF PLANE/VSWR (S401) — VSWR.
   VSWR % FULL SCALE (R408) — 4.
   INPUT SIGNAL LEVEL (R111) — 1 mV.

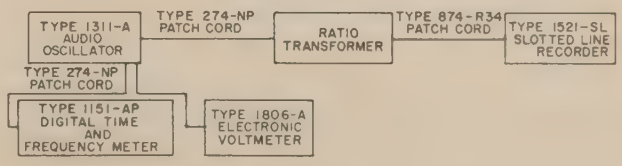

TYPE 1311-A AUDIO OSCILLATOR
TYPE 274-NP PATCH CORD
RATIO TRANSFORMER
TYPE 874-R34 PATCH CORD
TYPE 1521-SL SLOTTED LINE RECORDER
TYPE 274-NP PATCH CORD
TYPE 1151-AP DIGITAL TIME AND FREQUENCY METER
TYPE 1806-A ELECTRONIC VOLTMETER

Figure 6-1. Setup for minimum-performance testing and calibration of Type 1521-SL/SLQ1 recorder.

TABLE 6-1
RECOMMENDED TEST EQUIPMENT (See Figure 6-1)

Function	*Type or Model**	*Remarks*
Audio oscillator	General Radio 1311-A	Frequency and amplitude stabilities must be 0.01%, or better.
Electronic voltmeter	General Radio 1806-A	Accuracy should be ±2%.
Digital counter	General Radio 1151-AP Digital Frequency Meter	Type 1150-A also recommended.
Ratio transformer	Gertsch RT-5	Should be settable to 6 decimal places.
Patch cords, double plug (2)	General Radio 274-NP	Permit stacking for multiple connections.
Patch cord, coaxial	General Radio 874-R34	Binding post plug one end, GR874 coaxial connector on the other.
Tuned null detector†	General Radio 1232-A Tuned Amplifier and Null Detector.	Microvolt sensitivity required.
Metered variable autotransformer †	General Radio W5MT3AW Variac® autotransformer	Voltage and current indicators required.

* Or equivalent
† Required for trouble-analysis use only.

NOTE

Procedures of paragraph 6.5 predicated on use of chart paper P/N 1521-9428.

CENTERING (R112) — 12 o'clock.
DAMPING (R22) — approximately ¼-turn from full CW.

6.5.3 AMPLIFIER BANDWIDTH AND TUNING CALIBRATION.

The procedures are as follows:

a. Adjust the INPUT SIGNAL LEVEL control slightly around 1 mV to bring the pen on scale at 0 dB, i.e., edge rule of chart paper at right.

b. See that the SET LEVEL meter (M401) indicates within the black wedge.

c. Bring the pen to the center of the chart with the CENTERING control.

d. Adjust the ΔF control on the oscillator slightly to obtain a maximum pen deflection to the left and observe the frequency on the counter. It should be 990 ±20 c/s, the peak frequency of the tuned amplifier.

e. Return the pen to midscale with the CENTERING control and set the ratio transformer to X.001414. The pen will move off scale to the left.

f. With the ΔF control, increase the oscillator frequency until the pen returns to midchart and record the counter indication.

g. Decrease the ΔF setting through 0 until the pen has traveled off scale once more and ultimately has returned to midchart. Again record the frequency indicated by the counter.

h. Subtract the reading in step g from the reading in step h to obtain 3-dB bandwidth. This should be 35 ±7 c/s.

6.5.4 VSWR % FULL SCALE CONTROL CALIBRATION.

Continue with the same setup.

a. Return the ratio transformer to X.001000 and set the VSWR % FULL SCALE control to 20; the pen should be at the right-hand edge rule. A slight reduction in INPUT SIGNAL LEVEL setting may be required to get the pen on scale.

b. Reduce the setting of the INPUT SIGNAL LEVEL sufficiently to move the pen 1 major division to the left on the chart paper. Use the CENTERING control to set the pen precisely on the ruling.

c. Set the ratio transformer to X.001320 ($1.15^2 \times 10^{-3}$). The pen should move to the left 6 major divisions and come to rest on the first major division in from that edge, within 0.5 minor division.

d. Reset the ratio transformer to X.001000 and change the VSWR % FULL SCALE setting to 8. Reset the pen on the first major division in from the right-hand edge.

e. Set the ratio transformer to X.001124 and observe that the pen moves six major divisions to the left (within 0.5 minor division).

f. Reset the ratio transformer to X.001000 and change the VSWR % FULL SCALE setting to 4. Reset the pen on the first major division in from the right-hand edge.

g. Set the ratio transformer to X.001060 and observe that the pen moves to the left six major divisions.

h. Reset the ratio transformer to X.001000 and change the VSWR % FULL SCALE setting to 2. Reset the pen on the first major division in from the right-hand edge.

i. Set the ratio transformer to X.001030 and observe that the pen moves again to the left six major divisions (within 0.5 minor division).

j. Reset the ratio transformer to X.001000 and change the VSWR % FULL SCALE setting to 0.8. Reset the pen on the first major division in from the right-hand edge.

k. Set the ratio transformer to X.001012 and observe that the pen moves to the left six major divisions (within 0.5 minor division).

6.5.5 REF PLANE OPERATION.

To check the calibration of the recorder operated in its REF PLANE mode, continue with the same setup as in paragraph 6.5.4 and proceed as follows:

a. Reset the VSWR % FULL SCALE control to 4 and the ratio transformer to X.001000.

b. Set the pen to midscale with the INPUT SIGNAL LEVEL control.

c. Place switch S401 in the REF PLANE position and observe that the pen moves off scale to the left.

d. Change the ratio transformer setting to return the pen to midscale. The setting should be X.000100 ±0.000025.

e. Return S401 to the VSWR position.

6.5.6 VSWR TRACKING CHECK.

Continue with the same setup. The tracking error in steps c to f below should be less than one minor division; in step g, less than one half of one minor division.

a. Return the ratio transformer to X.001000 and VSWR % FULL SCALE control to 20.

b. Adjust the INPUT SIGNAL LEVEL control slightly around 1 mV to set the pen on the ruling at the right-hand edge of the chart.

c. Set the ratio transformer to X.001100 and observe that the pen moves two major divisions to the left.

d. Set the ratio transformer to X.001210 and observe that the pen moves two major divisions to the left (midscale).

e. Set the ratio transformer to X.001320 and observe that the pen moves two major divisions farther to the left.

f. Set the ratio transformer to X.001440 and observe that the pen moves to the left-hand edge ruling on the chart paper.

g. Reset the ratio transformer to X.001000, set the VSWR % FULL SCALE control to 4, and repeat the process of steps a through f above, substituting values as follows:

Chart Position *Major Divisions from Left*	*Ratio Transformer Setting*
0	X.001000
2	X.001020
4	X.001040
6	X.001060
8	X.001081

6.6 TROUBLE ANALYSIS.

6.6.1 GENERAL.

In the event system performance is impaired and the deficiency is isolated to the recorder component through the procedures of paragraph 6.5, the trouble-analysis procedures appearing in Table 6-2 will help to isolate defects to major subassemblies within the recorder.

Secondary controls within amplifier chains provide adequate flexibility to compensate for aging effects, or changes as the result of adverse environmental conditions.

Most major subassemblies can be replaced as a unit, should this be necessary. In addition, all transistors (except power types) are socket-mounted for easy replacement from field supplies.

6.6.2 SECONDARY CONTROLS AND INDICATORS.

Controls and indicators found elsewhere than on the front panel, and useful in the trouble analysis and calibration adjustment of the recorder, are listed and described in Table 6-3.

TABLE 6-2.
RECORDER TROUBLE ANALYSIS
(See Figures 6-2 through 6-5)

Step	*Trouble*	*Probable Cause*	*Remedy*
a	Chart area not illuminated when POWER switch is on.	1. Fuses F1 or F2 open. 2. Lamps P1 & P2 burned out.	Replace defective parts
b	No chart drive	Limit switches S7 and S8 both open.	Reset switches for at least slight radial separation, or place S6 in OUT position.
c	No indication on SET LEVEL meter (with signal input).	1. 18-V dc supply failure. 2. Broken lead in PL2. 3. Broken lead to wiper arm of R409 4. R403 set fully CW. 5. R407 fully CW. 6. Meter, M401, defective. 7. Q400-Q402 defective. 8. Q101 or Q102 defective. 9. Q103 or Q104 defective. 10. Q105, Q106 defective.	1. Refer to step m. 2. Repair 3. Repair. 4. Adjust. Refer to step k. 5. Adjust. Refer to step d. 6. Replace. 7. Look for 1.9 ±0.2 V dc drop across R402. If indication abnormal, refer to Table 6-4 to isolate defective unit and replace. 8. Look for 2.5 ±0.2 V dc drop across R109. If indication abnormal, refer to Table 6-4 to isolate defective unit and replace. 9. Look for 2.0 ±0.2 V dc drop across R123. If indication abnormal, refer to Table 6-4 to isolate defective unit and replace. 10. Refer to Table 6-4 to isolate defective unit and replace.
d	SET LEVEL meter indicates outside black wedge for pen deflection on chart paper.	Improperly calibrated.	Use test setup of paragraph 6.5 and adjust screwdriver-potentiometer R407 (Figure 6-3) to reposition needle for center-wedge deflection with pen on chart paper.
e	No pen movement (SET LEVEL meter indication within wedge).	1. Broken lead to servomotor, or drive coil defective. 2. Q108-Q113; Q1, Q2 defective.	1. Refer to paragraph 6.8. 2. Refer to Table 6-4 to isolate defective unit and replace.
f	Severe pen vibration (i.e., several major divisions, continuous).	1. DAMPING control, R22, set too far CCW. 2. Broken lead to servo motor, or defective feedback coil. 3. R130 out of adjustment.	1. Readjust. 2. Refer to paragraph 6.8. 3. Adjust (refer to paragraph 6.7).
g	Pen drift (with constant input).	1. Broken lead in PL2. 2. R130 improperly set.	1. Repair or replace. 2. Adjust (refer to paragraph 6.7).
h	Erratic operation of pen with constant-level input signal.	1. Dirty winding in servobalance potentiometer, R409. 2. R130 improperly set. 3. Noisy transistors Q400, Q101, or Q103. 4. 18-V dc supply not regulating properly.	1. Remove assembly and inspect for wear or damage. Clean winding and contact arm (paragraph 6.3.4). 2. Adjust (refer to paragraph 6.7). 3. Replace if defective. 4. Refer to step m.

TABLE 6-2. continued

Step	*Trouble*	*Probable Cause*	*Remedy*
i	VSWR % FULL SCALE dial out of calibration.	1. Broken lead in PL2. 2. Broken lead to R408. 3. R409 defective. 4. R408 defective.	Repair or replace defective parts.
j	Width of recorded minima on REF PLANE position too broad.	1. S401 defective. 2. R403 improperly set. 3. R403 defective.	1. Replace. 2. Adjust (refer to step k). 3. Replace.
k	INPUT SIGNAL LEVEL control out of calibration.	1. R403 improperly set. 2. INPUT SIGNAL LEVEL control, R111, defective. 3. CENTERING control, R112, defective.	1. Adjust with 1 mV input, 4% VSWR scale, 1 mV ISL control setting, for pen deflection on chart paper. 2. Replace. 3. Replace.
l	CENTERING control inoperative.	R112 defective.	Replace.
m	18-V dc supply malfunction.	1. 26-V dc supply inoperative. 2. Q114 or Q115 defective. 3. Q116 defective. 4. Reference diode, CR107, defective. 5. R168 out of adjustment.	1. Refer to step n. 2. Look for 0.85 ±0.1 V dc drop across R161 or R162. If indication abnormal, refer to Table 6-4 to isolate defective part, and replace. 3. Look for 3.0 ±0.2 V dc drop across R164. If indication abnormal, refer to Table 6-4 to isolate defective part, and replace. 4. Look for 6.8 ±0.5 V dc across CR107; replace if indication abnormal. 5. Look for 18 V dc ±5% at TP109 (Figure 6-4). Adjust R168 if necessary.
n	26-V dc supply malfunction.	1. P201 (series-dropping-resistor bulb) open. 2. CR1 or CR2 open. 3. C2 or C3 defective. 4. Q3 defective. 5. CR110 or CR111 defective.	1-4. Look for 26 ±1.5 V dc at TP111. Replace defective parts. 5. Look for 8.2 V dc ±5% across CR110; 18 V dc ±5% across CR111. Replace if indication abnormal.
o	Sine-wave pattern of VSWR plot distorted.	1. Mechanical resistance to pen motion. 2. Excessive wiper-arm contact pressure on R409.	1. Wipe guide rods clean. Do not oil. Clean, repair, or adjust other parts to eliminate excessive friction. 2. Bend arm down slightly to reduce pressure.
p	Line-voltage fluctuation sensitivity (see Figure 6-6).	1. 26-V dc supply not regulating. 2. 18-V dc supply not regulating.	1. Refer to step n. 2. Refer to step m.

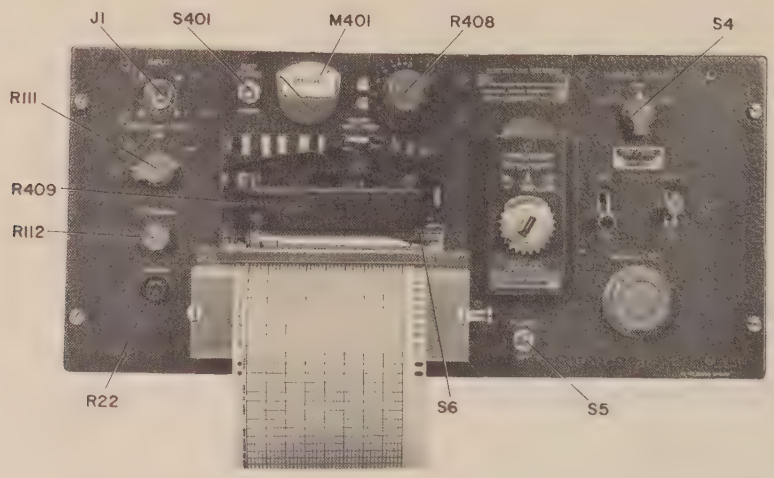


Figure 6-2. Front panel controls and indicators of Type 1521-SL recorder.

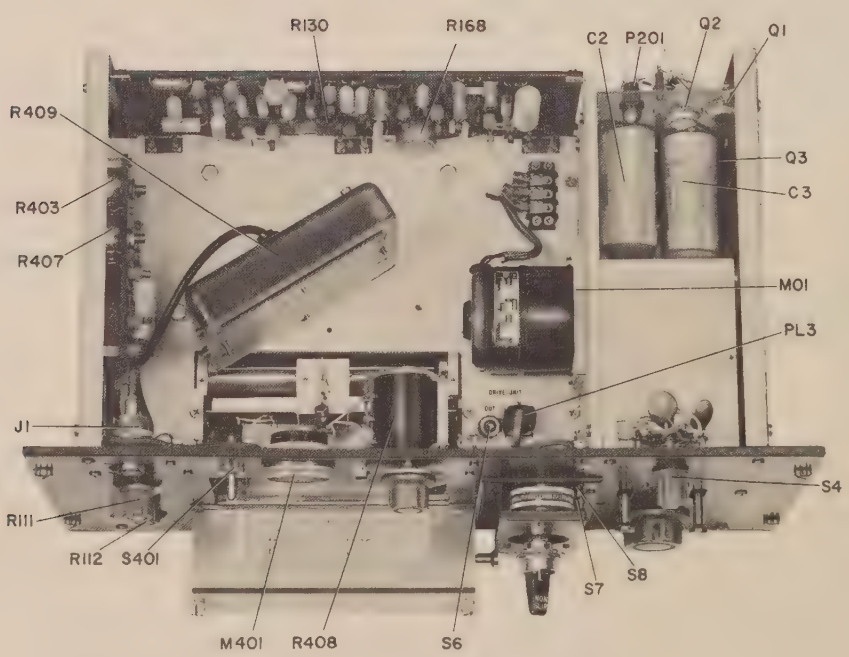


Figure 6-3. Top interior of Type 1521-SL recorder shown with R409 tipped up and shield removed from preamplifier at left.

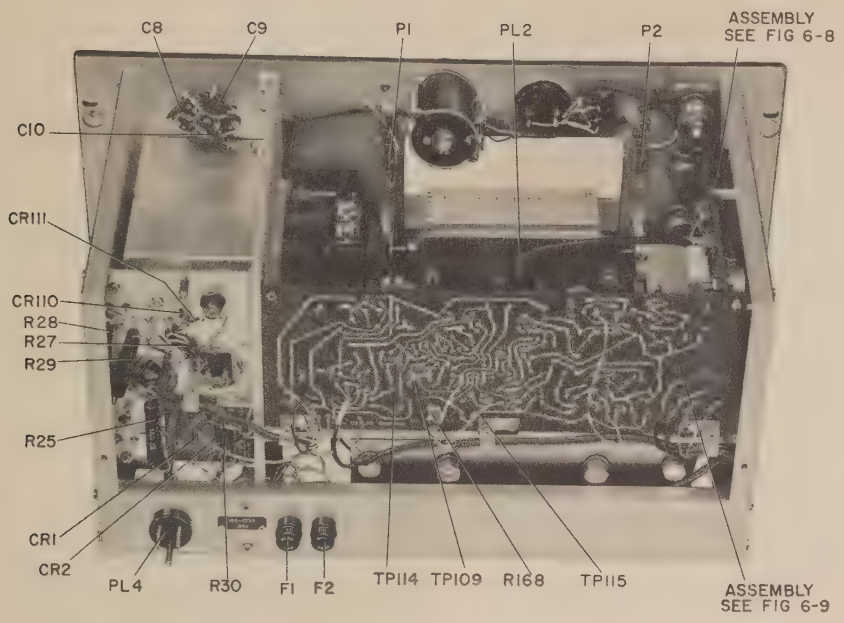


Figure 6-4. Rear interior of Type 1521-SL recorder.

TABLE 6-3
SECONDARY CONTROLS AND INDICATORS

Ref Desig	*Location*	*Type*	*Function*	*See Figure*
R403	Interior: Assembly 1521-0730/4	Screwdriver-adjustment potentiometer	Preamplifier gain adjustment	6-3
R130	Interior: Assembly 1521-0710/3	Screwdriver-adjustment potentiometer	Push-pull amplifier balance control	6-3
R407	Interior: Assembly 1521-0730/4	Screwdriver-adjustment potentiometer	Meter calibration adjustment	6-3
R168	Exterior-rear: Assembly 1521-0710/3	Screwdriver-adjustment potentiometer	Regulated supply voltage adjustment (+18 V dc)	6-4
S6	Interior-front: Main Chassis	SPST toggle switch	Disables drive unit limit switches (S7, S8) in OUT position	6-3
P1/P2	Interior; paper well	Incandescent lamps	Glow when POWER on	6-4

6.7 AMPLIFIER OUTPUT BALANCE ADJUSTMENTS.

An imbalance between the outputs of transistors Q105 and Q106 will result in improper operation of the detector-limiter stage with consequent erratic pen action in the recorder. The balance is controlled by potentiometer R130 (see Figure 6-3).

To adjust the balance, set up the recorder in the test arrangement of paragraph 6.5 and, with clip leads, connect TP114 and TP115 (Figure 6-4) to the input of a Type 1232-A Tuned Amplifier and Null Detector. Adjust the detector for operation at approximately 1 kc/s, LINEAR meter scale. Set the gain for an upscale indication and peak the FILTER TUNING control in the region of 1 kc/s.

CAUTION

Do not connect either test lead to ground. Let the chassis of the Type 1232-A float above ground. Adjust R130 on the recorder for minimum indication on the Type 1232-A detector.

6.8 SERVO-MOTOR CHECKS (See Figure 6-5).

Improper pen action, as a result of defects in the servo-motor coil, as indicated in Table 6-2, can be isolated by the procedures that follow:

a. Remove all power and input signals from the recorder, remove the case, and turn the recorder upside down on the bench.

b. Inspect the assembly for defective wiring.

c. To check the drive coil, release the screws at the rear of the Jones strip for terminals AT6, AT7, and AT8, and remove the leads.

d. With an ohmmeter, look for 41 ohms ±3% between AT7 and AT6 and between AT7 and AT8. If either indication is abnormal, the coil is defective and the assembly must be replaced.

e. To check the feedback coil, release the screws at the rear of the Jones strip at terminals AT9 and AT10 and remove the leads.

f. With an ohmmeter, look for 250 ohms ±5% between the terminals. If the indication is abnormal, the coil is defective and the assembly must be replaced.

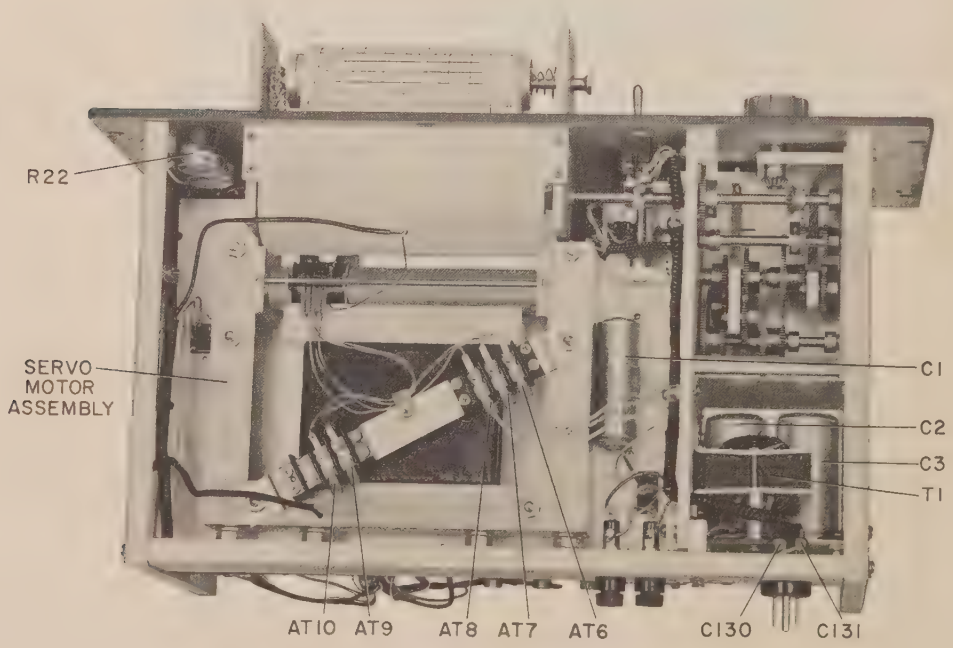


Figure 6-5. Bottom interior view of Type 1521-SL recorder.

TABLE 6-4
TRANSISTOR VOLTAGE CHART
DC VOLTS TO GROUND

Transistor	Lead	Volts - DC		Supply Volts
		No Input	AC Input	
Q1	B	18.2	20.5	26 V dc ±10%
	C	18.3	11.2	
	E	18.4	20.6	
Q2	B	24.8	20.5	
	C	9.1	11.2	
	E	18.3	20.6	
Q3	B	-0.16	-0.16	
	C	9.0	9.0	
	E	0	0	
Q101	B	5.3	5.3	18 V dc ±5%
	C	7.8	7.8	
	E	4.7	4.7	
Q102	B	7.8	7.8	
	C	11.2	11.2	
	E	7.2	7.2	
Q103	B	4.2	4.2	
	C	8.0	8.0	
	E	3.7	3.7	
Q104	B	8.0	8.0	
	C	15.2	15.2	
	E	7.5	7.5	
Q105	B	3.5	3.5	
	C	7.1	7.1	
	E	2.9	2.9	
Q106	B	1.8	1.8	
	C	8.8	8.8	
	E	1.2	1.2	
Q108	B	11.5	10.5	
	C	12.5	15.0	
	E	11.0	10.0	
Q109	B	10.5	10.5	
	C	17.5	15.0	
	E	10.0	9.9	

Transistor	Lead	Volts - DC		Supply Volts
		No Input	AC Input	
Q110	B	11.8	14.2	26 V dc ±5%
	C	26.0	20.2	
	E	15.9	13.6	
Q111	B	16.5	14.2	
	C	18.0	20.2	
	E	15.9	13.6	
Q112	B	26.0	20.2	
	C	17.6	9.2	
	E	24.8	20.4	
Q113	B	18.0	20.2	
	C	17.7	9.2	
	E	18.2	20.4	
Q114	B	26.3	26.3	Not Applicable
	C	21.0	21.0	
	E	26.6	26.6	
Q115	B	26.3	26.3	
	C	21.0	21.0	
	E	26.6	26.6	
Q116	B	11.9	11.9	
	C	23.2	23.2	
	E	11.4	11.4	
Q400	B	1.2	1.2	18 V dc ±5%
	C	7.0	7.0	
	E	0.8	0.8	
Q401	B	7.0	7.0	
	C	16.0	16.0	
	E	6.5	6.5	
Q402	B	6.5	6.5	
	C	16.0	16.0	
	E	5.9	5.9	

CONDITIONS:

° Measurements made with a Type 1806-A Electronic Voltmeter, or equivalent. (A 20 kΩ /V VOM is unsuited for this use.)

° AC Input — 1 kc/s at 1 mV with VSWR % FULL SCALE at 4 and INPUT SIGNAL LEVEL at 1 mV; pen on scale.

6.9 POWER-LINE SENSITIVITY.

To determine recorder sensitivity to 115-V ac line changes, and as a gross indication of power-supply failure, perform the following procedures:

a. Connect the recorder to the 115-V ac line through a Type W5MT3AW metered Variac® adjustable autotransformer set for 115-V ac output.

b. Turn the POWER switch of the recorder on and observe an input power indication of 25 ±2 W. If the indication is abnormal, refer to Table 6-4 for a detailed voltage check inside the instrument.

c. Connect a 1-mV, 1-kc source (Type 1311-A or equivalent) to the input of the recorder.

d. Set the VSWR % FULL SCALE control to 0.8 and adjust the DAMPING control for optimum pen jitter.

e. Bring the pen to midscale with the INPUT SIGNAL LEVEL and CENTERING controls.

f. Set the CHART DRIVE control for 10 DIV/MIN paper speed and run a plot similar to that of Figure 6-6, varying the input voltage as indicated.

The plot of a properly functioning recorder should correspond to the sample shown.

6.10 SLOTTED-LINE FLATNESS CHECK.

The Type 1521-SL Recorder can be used to determine the effectiveness of flatness adjustments performed on the Type 900-LB Precision Slotted Line portion of the system, in accordance with service procedures given in the slotted-line manual. In such use, the recorder can speed up flatness adjustments significantly.

NOTE

This procedure should *never* be required unless the line has been damaged, disassembled or otherwise physically altered.

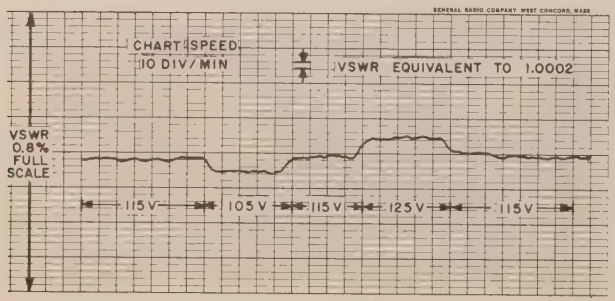


Figure 6-6. Maximum sensitivity to line-voltage variations for a properly functioning recorder.

The audio-frequency flatness measurement is performed as follows:

a. Assemble the system in the usual manner, except leave the load-end connector on the line unterminated.

b. Make sure that the diode detector and the probe-tuner assembly have been removed from the slotted-line carriage.

c. Install the rf probe assembly (supplied with the line), and turn the probe slowly in with a screwdriver until it gently touches the center conductor of the line, as indicated by a voltohmmeter placed across the probe and the center conductor of the GR874 connector at the input end of the line.

CAUTION

Damage to the probe and the slotted-line inner conductor will result if the probe is driven beyond the point of just touching the inner conductor.

d. Back off the probe six full turns.

e. Connect the recorder INPUT directly to the rf probe on the line.

f. Connect a Type 1311-A Audio Oscillator directly to the input of the slotted line with a Type 874-R34 Patch Cord.

g. Set the oscillator for approximately 60-V output at 1 kc/s.

WARNING

The line will be driven at unusually high voltage for this procedure.

h. Set the recorder INPUT SIGNAL LEVEL control to 0.3 mV, the VSWR % FULL SCALE control to 1. In this procedure (i.e., without the square-law crystal detector) this setting corresponds to a VSWR of 2% full scale.

i. Move the probe carriage to 58 cm, center the pen on the paper, and run a plot the full length of the line as shown in Figure 6-7. Total flatness curve should fit within 4 major divisions (±0.5%) on the chart paper.

6.11 OTHER SERVICE PROBLEMS.

The following service problems should be referred to the factory:

(1) Replacement of parts on the servo-motor assembly (see Figure 6-5), including potentiometer contact and drive-coil assembly.

(2) Other mechanical problems in the gear box, paper-drum, or chart-drive mechanisms.

(3) Electronic problems other than those listed in trouble-analysis (Table 6-2).

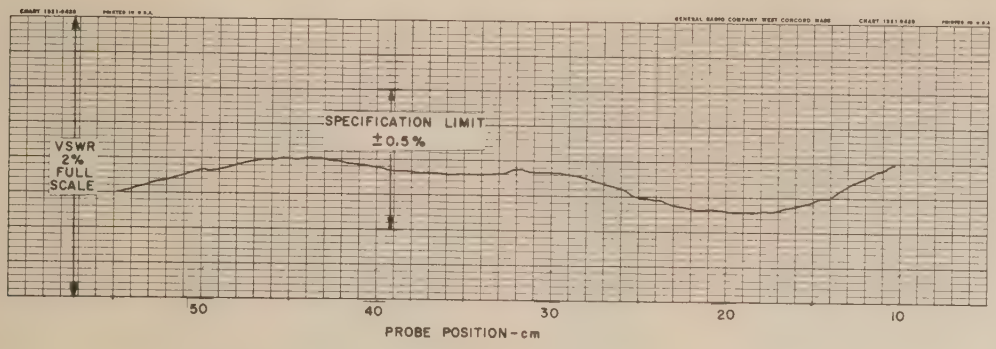


Figure 6-7. Typical 1-kc flatness plot of a Type 900-LB Slotted Line run on the Type 1521-SL recorder.

PARTS LIST FOR TYPE 1521-SL

Parts List for Type 1521-SLQ1 same except for motor;

M01 MOTOR, synchronous, 50 cycle 5760-1700

RESISTORS

Ref No.	Description	Part No.	Ref No.	Description	Part No.
R22	Potentiometer, Wire-Wound, 250Ω +10%	6050-0900	R124	Composition, 100 kΩ ±5% 1/2w	6100-4105
R23	Composition, 1.5 kΩ ±5% 1/2w	6100-2155	R125	Composition, 27 kΩ ±5% 1/2w	6100-3275
R24	Composition, 10 kΩ ±5% 1/2w	6100-3105	R126	Composition, 6.8 kΩ ±5% 1/2w	6100-2685
R25	Power, 1.8 Ω ±5% 10w	6670-9185	R127	Composition, 820 Ω ±5% 1/2w	6100-1825
R27	Power, 22 Ω ±5% 5w	6660-0225	R128	Composition, 1 kΩ ±5% 1/2w	6100-2105
R28	Power, 82 Ω ±5% 10w	6670-0825	R129	Composition, 6.8 kΩ ±5% 1/2w	6100-2685
R29	Power, 82 Ω ±5% 10w	6670-0825	R130	Potentiometer, Composition, 2.5 kΩ ±20%	6040-0500
R30	Composition, 30 Ω ±10% 2w	6120-0305	R131	Composition, 1 kΩ ±5% 1/2w	6100-2105
R101	Composition, 3.3 mΩ ±5% 1/2w	6100-5335	R132	Composition, 100 kΩ ±5% 1/2w	6100-4105
R102	Composition, 2 kΩ ±5% 1/2w	6100-2205	R133	Composition, 12 kΩ ±5% 1/2w	6100-3125
R103	Composition, 100 kΩ ±5% 1/2w	6100-4105	R135	Composition, 18 kΩ ±5% 1/2w	6100-3185
R104	Composition, 18 kΩ ±5% 1/2w	6100-3185	R136	Composition, 20 kΩ ±5% 1/2w	6100-3205
R105	Composition, 33 kΩ ±5% 1/2w	6100-3335	R138	Composition, 240 Ω ±5% 1/2w	6100-1245
R106	Composition, 10 kΩ ±5% 1/2w	6100-3105	R142	Composition, 2.4 kΩ ±5% 1/2w	6100-2245
R107	Composition, 33 kΩ ±5% 1/2w	6100-3335	R143	Composition, 3.3 kΩ ±5% 1/2w	6100-2335
R108	Composition, 33 kΩ ±5% 1/2w	6100-3335	R144	Composition, 3.3 kΩ ±5% 1/2w	6100-2335
R109	Composition, 5.6 kΩ ±5% 1/2w	6100-2565	R150A	Composition, 18 kΩ ±5% 1/2w	6100-3185
R110	Composition, 1.6 kΩ ±5% 1/2w	6100-2165	R151A	Composition, 18 kΩ ±5% 1/2w	6100-3185
R111	Potentiometer, Composition, 250 kΩ ±10%	0020-0800	R153	Composition, 10 kΩ ±5% 1/2w	6100-3105
R112	Potentiometer, Composition, 100 Ω ±10%	6040-1730	R154	Composition, 10 kΩ ±5% 1/2w	6100-3105
R113	Composition, 1.1 kΩ ±5% 1/2w	6100-2115	R155	Composition, 10 kΩ ±5% 1/2w	6100-3105
R114	Film, 475 kΩ ±1% 1/4w	6350-3475	R156	Composition, 1.6 kΩ ±5% 1/2w	6100-2165
R115	Composition, 62 kΩ ±5% 1/2w	6100-3625	R157	Composition, 1.6 kΩ ±5% 1/2w	6100-2165
R116	Film, 232 kΩ ±1% 1/4w	6350-1232	R158	Composition, 1 kΩ ±5% 1/2w	6100-2105
R117	Film, 232 kΩ ±1% 1/4w	6350-1232	R159	Composition, 820 Ω ±5% 1/2w	6100-1825
R118	Film, 536 Ω ±1% 1/4w	6350-0536	R160	Composition, 910 Ω ±5% 1/2w	6100-1915
R119	Composition, 120 kΩ ±5% 1/2w	6100-4125	R161	Composition, 100 Ω ±5% 1/2w	6100-1105
R120	Composition, 560 Ω ±5% 1/2w	6100-1565	R162	Composition, 100 Ω ±5% 1/2w	6100-1105
R121	Film, 2.21 kΩ ±1% 1/4w	6350-1221	R163	Composition, 470 kΩ ±5% 1/2w	6100-4475
R122	Film, 3.32 kΩ ±1% 1/4w	6350-1332	R164	Composition, 180 Ω ±5% 1/2w	6100-1185
R123	Composition, 1.5 kΩ ±5% 1/2w	6100-2155			

RESISTORS cont

Ref No	Description	Part No.
R165	Composition, 18 kΩ ±5% 1/2w	6100-3185
R166	Composition, 2 kΩ ±5% 1/2w	6100-2205
R167	Composition, 4.7 kΩ ±5% 1/2w	6100-2475
R168	Potentiometer, Composition, 2.5 kΩ ±5%	6010-0700
R169	Composition, 10 kΩ ±5% 1/2w	6100-3105
R170	Composition, 6.8 kΩ ±5% 1/2w	6100-2685
R171	Composition, 51 Ω ±5% 1/2w	6100-0515
R173	Composition, 1.5 kΩ ±5% 1/2w	6100-2155
R205	Composition, 30 kΩ ±5% 1/2w	6100-3305
R206	Composition, 15 mΩ ±5% 1/2w	6100-6155
R400	Composition, 3.3 mΩ ±5% 1/2w	6100-5335
R401	Composition, 2.2 mΩ ±5% 1/2w	6100-5225
R402	Composition, 3.3 kΩ ±5% 1/2w	6100-2335
R403	Potentiometer, Composition, 10 kΩ ±10%	6030-0150
R404	Composition, 220 kΩ ±5% 1/2w	6100-4225
R405	Composition, 220 kΩ ±5% 1/2w	6100-4225
R406	Composition, 68 kΩ ±5% 1/2w	6100-3685
R407	Potentiometer, Composition, 50 kΩ ±10%	6010-1400
R408A	Potentiometer, Wire-Wound, special taper	0973-4310
R408B	Potentiometer, Wire-Wound, special taper	
R409	Potentiometer, Wire-Wound, in-line	1521-2180
R410	Film, 1 kΩ ±1% 1/4w	6350-1100
R411	Film, 51.1 Ω ±1% 1/4w	6350-9511
R412	Composition, 10 kΩ ±5% 1/2w	6100-3105
R413	Film, 1.47 kΩ ±1% 1/4w	6350-1147

CAPACITORS

C1	Oil, 1μF 220v	4510-5020
C2A	Electrolytic, 400μF 75v	4450-4000
C2B	Electrolytic, 200μF 75v	4450-4000
C2C	Electrolytic, 200μF 75v	4450-4000
C3A	Electrolytic, 400μF 75v	4450-4000
C3B	Electrolytic, 200μF 75v	4450-4000
C3C	Electrolytic, 200μF 75v	4450-4000
C8	Ceramic, 0.022μF +80-20%	4407-3229
C9	Ceramic, 0.022μF +80-20%	4407-3229
C10	Ceramic, 0.047μF +80-20% 500v	4409-3479
C101	Plastic, 0.22μF ±10% 100v	4860-7981
C102	Electrolytic, 5μF +100-10% 50v	4450-3900
C103	Electrolytic, 10μF +100-10% 25v	4450-3800
C104	Ceramic, 0.1μF +80-.20% 50v	4403-4100
C105	Electrolytic, 5μF +100-10% 50v	4450-3900
C106	Plastic, 0.22μF ±10% 100v	4860-7981
C107	Electrolytic, 5μF +100-10% 50v	4450-3900
C108	Plastic, 0.1μF ±2% 100v	4860-8251
C109	Plastic, 0.1μF ±2% 100v	4860-8251
C110	Plastic, 0.1μF ±2% 100v	4860-8251
C111	Electrolytic, 10μF +100-10% 25v	4450-3800
C112	Plastic, 0.22μF ±10% 100v	4860-7981
C113	Ceramic, 0.1μF +80-20% 50v	4403-4100
C114	Electrolytic, 5μF +100-10% 50v	4450-3900
C115	Electrolytic, 5μF +100-10% 50v	4450-3900
C116	Plastic, 0.22μF ±10% 100v	4860-7981
C117	Ceramic, 0.01μF +80-20% 50v	4860-7750
C119	Ceramic, 0.01μF +80-20% 50v	4860-7750
C120	Ceramic, 0.01μF +80-20% 50v	4860-7750
C121	Plastic, 0.22μF ±10% 100v	4860-7981
C122	Plastic, 0.22μF ±10% 100v	4860-7981
C123	Plastic, 0.047μF ±10% 100v	4860-8200
C124	Plastic, 0.1μF ±10% 100v	4860-8250
C125	Plastic, 1μF ±10% 100v	4860-8274
C126	Plastic, 0.01μF ±10% 100v	4860-7750
C127	Electrolytic, 5μF +100-10% 50v	4450-3900
C128	Plastic, 0.1μF ±10% 100v	4860-8250
C129	Plastic, 0.01μF ±10% 100v	4860-7750
C130	Ceramic, 0.0068μF +80-20% 500v	4406-2689
C131	Ceramic, 0.01μF +80-20% 500v	4406-3190
C400	Plastic, 0.15μF ±10% 600v	4860-9400

CAPACITORS cont

Ref No.	Description	Part No.
C401	Electrolytic, 1μF ±20% 35v	4450-4300
C402	Electrolytic, 15μF ±20% 20v	4450-5200
C403	Electrolytic, 6.8μF ±20% 6v	4450-4800
C404	Electrolytic, 4.7μF ±20% 10v	4450-4700

MISCELLANEOUS

CR1	DIODE, Type 1N3253	6081-1001
CR2	DIODE, Type 1N3253	6081-1001
CR101	DIODE, Type 1N191	6082-1008
CR102	DIODE, Type 1N191	6082-1008
CR103	DIODE, Type 1N191	6082-1008
CR104	DIODE, Type 1N191	6082-1008
CR107	DIODE, Type 1N957B	6083-1009
CR110	DIODE, Type 1N959B	6083-1010
CR111	DIODE, Type 1N967B	6083-1016
CR400	DIODE, Type 1N3253	6081-1001
CR401	DIODE, Type 1N3253	6081-1001
F1	FUSE, 115v: 1/2amp	5330-1000
	230v: 1/4amp	5330-0700
F2	FUSE, 115v: 1/2amp	5330-1000
	230v: 1/4amp	5330-0700
J1	JACK, Type 874-PRL58A	0874-9465
M401	METER, 0-50μA ±10% Marion-MM1	5730-1380
MO1	MOTOR, synchronous 60 cycle	5760-3064
P1	PILOT LAMP, 6.3v 1/4 amp Madza 44	5600-0700
P2	PILOT LAMP, 6.3v 1/4 amp Madza 44	5600-0700
P201	PILOT LAMP, 10v 0.015 amp GR 344	5600-0314
PL2	PLUG, Jones type, 4 prong (assembly)	1521-0401
PL3	PLUG, Jones type, 4 prong (assembly)	1521-0477
PL4	PLUG, 3 wire, panel GR 109A	0109-9701
Q1	TRANSISTOR, Type 2N176	8210-1760
Q2	TRANSISTOR, Type 2N176	8210-1760
Q3	TRANSISTOR, Type 2N1544	8210-1014
Q101	TRANSISTOR, Type 2N2714	8210-1047
Q102	TRANSISTOR, Type 2N2714	8210-1047
Q103	TRANSISTOR, Type 2N929	8210-1002
Q104	TRANSISTOR, Type 2N2714	8210-1047
Q105	TRANSISTOR, Type 2N2714	8210-1047
Q106	TRANSISTOR, Type 2N2714	8210-1047
Q108	TRANSISTOR, Type 2N2714	8210-1047
Q109	TRANSISTOR, Type 2N2714	8210-1047
Q110	TRANSISTOR, Type 2N2714	8210-1047
Q111	TRANSISTOR, Type 2N2714	8210-1047
Q112	TRANSISTOR, Type 2N1372	8210-1372
Q113	TRANSISTOR, Type 2N1372	8210-1372
Q114	TRANSISTOR, Type 2N1372	8210-1372
Q115	TRANSISTOR, Type 2N1372	8210-1372
Q116	TRANSISTOR, Type 2N2714	8210-1047
Q400	TRANSISTOR, Type 2N929	8210-1002
Q401	TRANSISTOR, Type 2N2714	8210-1047
Q402	TRANSISTOR, Type 2N2714	8210-1047
S4	SWITCH, Rotary, 3-position,	1521-3120
S5	SWITCH, Toggle, DPST	7910-1300
S6	SWITCH, Toggle, SPST	7910-1000
S7	SWITCH, Micro-Switch (V3-7), SPST	1521-0441
S8	SWITCH, Micro-Switch (V3-7), SPST	1521-0441
S401	SWITCH, Toggle, DPST	7910-0800
SO2	SOCKET, Jones S-304-AB	4230-3400
SO3	SOCKET, Jones S-304-AB	4230-4300
T1	TRANSFORMER	0345-4770

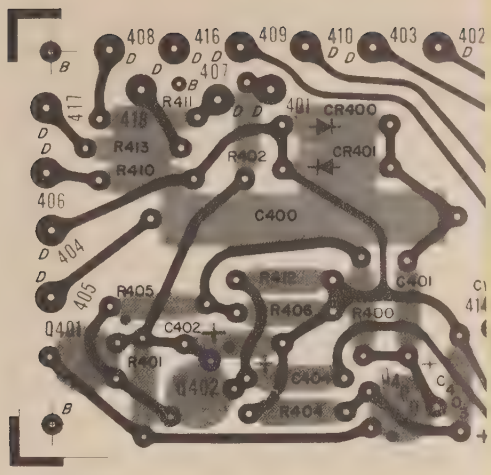


Figure 6-8. Etched-circuit a
which mounts preamplifier
attenuator circuits.

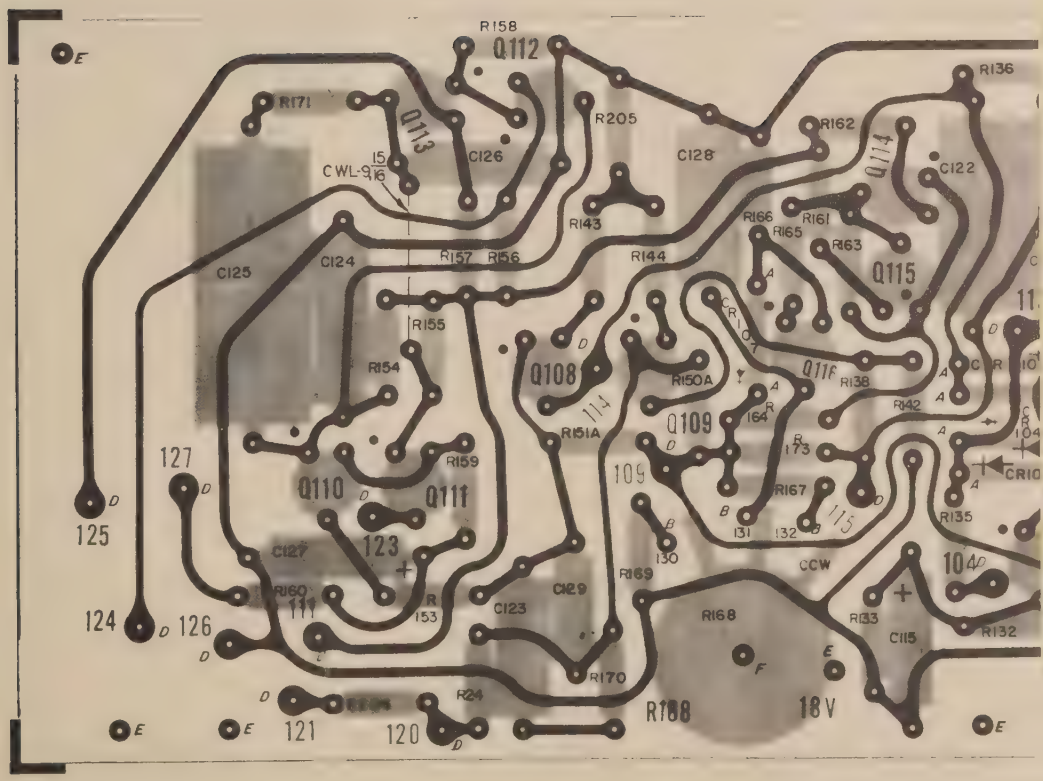
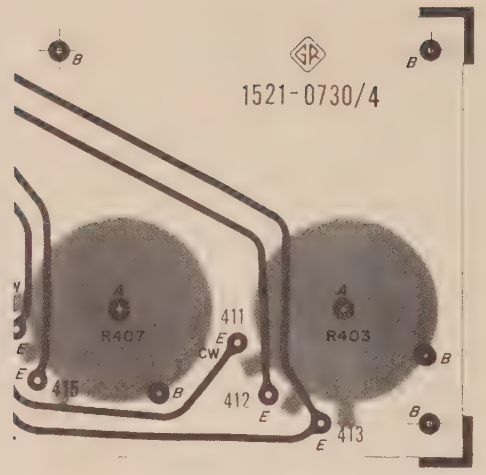
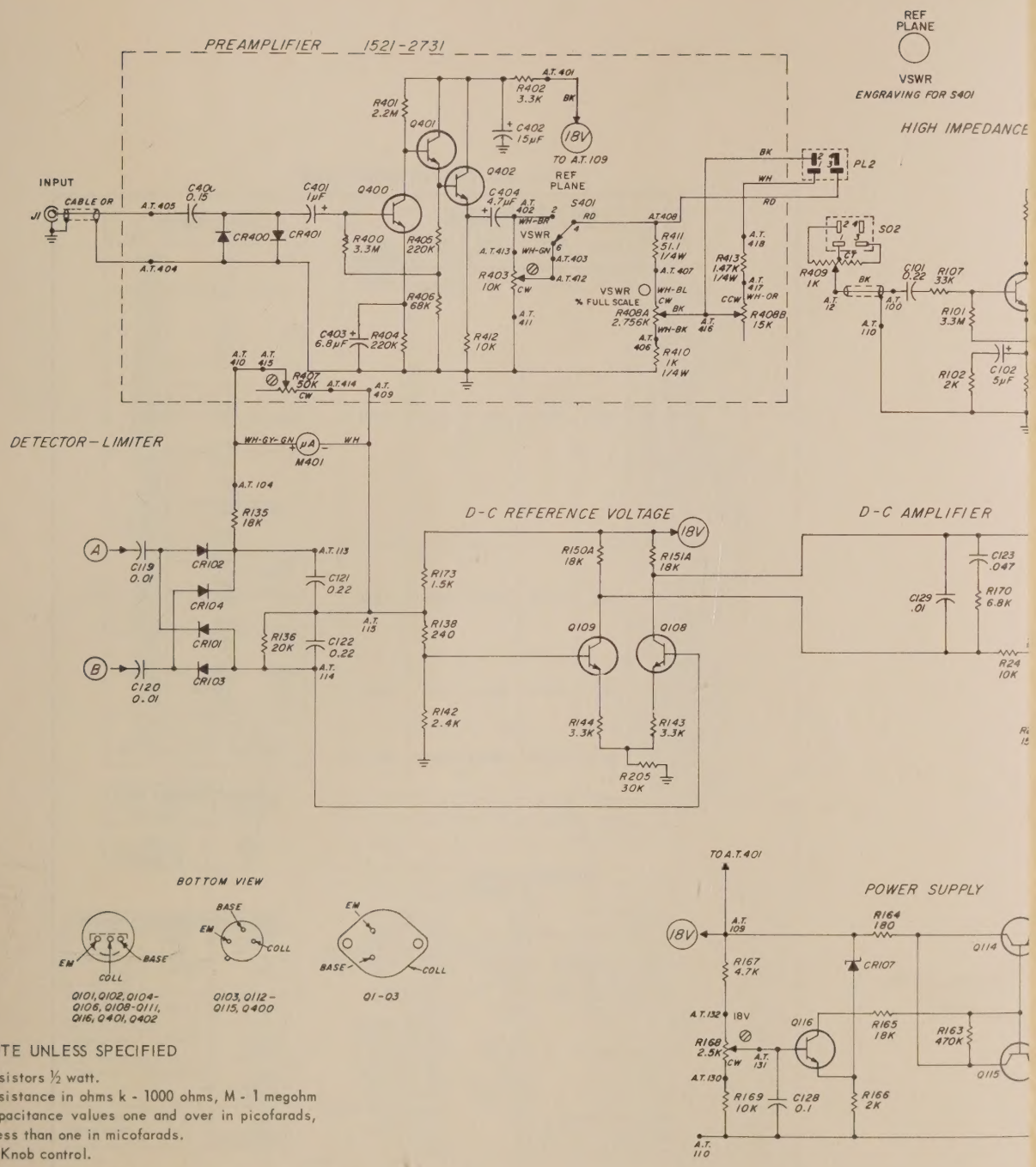


Figure 6-9. Etched-circuit a
which mounts servo amplif
lator circuits. Solder dots



ssembly (P/N 1521-0730/4),
and portions of the input

ssembly (P/N 1521-0710/3),
ier and power-supply regu-
indicate collector terminal.

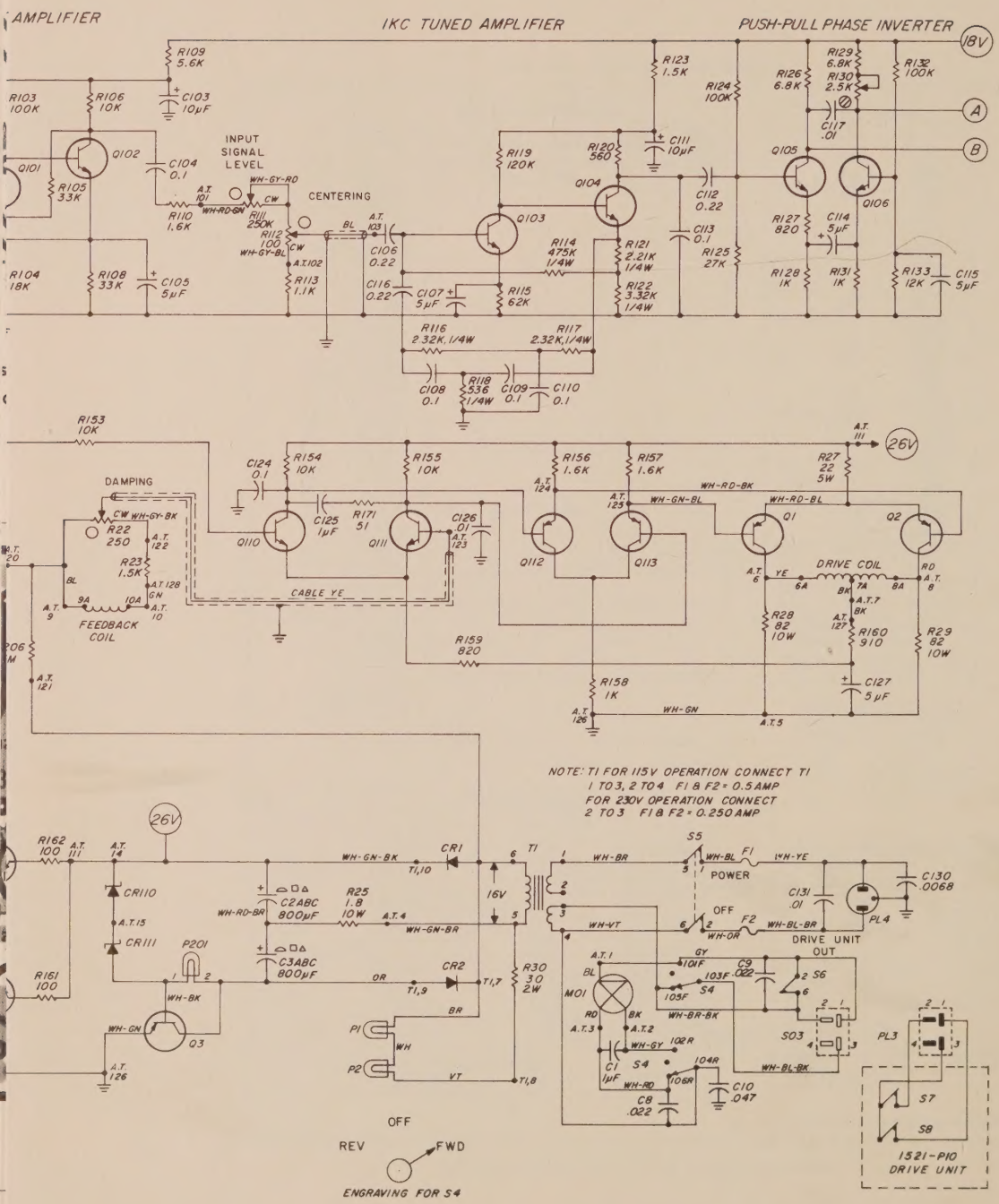


NOTE UNLESS SPECIFIED

Resistors ½ watt.
Resistance in ohms k - 1000 ohms, M - 1 megohm
Capacitance values one and over in picofarads, less than one in micofarads.
Knob control.
Screwdriver control.
AT - Anchor terminal.
TP - Test point.

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 6-10. Schematic diagram of Typ



e 1521-SL/SLQ1 Recorder.

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Printed in USA